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NUMBER 4



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Please direct correspondence to:

CAROL M. FERREL, *Editor*
Department of Fish and Game
722 Capitol Avenue
Sacramento 14, California

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REVIEW OF THE ABALONE OF CALIFORNIA¹

KEITH W. COX

Marine Resources Operations
California Department of Fish and Game

INTRODUCTION

In 1951 the Department of Fish and Game was directed by the State Legislature to expand its abalone investigation which had been in progress since 1939. Activities, at first concentrated in the area north of San Francisco, were later extended to include a major part of the central and southern California coastline and the Channel Islands. A preliminary report on the findings was presented to the Assembly Interim Committee on Fish and Game in August 1955; an article containing information on parts of the program was featured in *Outdoor California*, May 1957; *Notes on the California Abalone Fishery* were printed in Proceedings of the National Shellfish Association, 1958; a summary report was submitted to the Director of the Department of Fish and Game in November 1958; and, a detailed report on the investigation's findings in the coastal area north of San Francisco was presented to the State Legislature in March 1959.

In the course of the investigation a considerable amount of new information has been gathered and this report, which redescribes the species of abalone found in California, is based on some of these findings. Many conservationists, biologists, wardens and others who are charged with management and law enforcement are not able to identify all of the different species of abalone. Of the thousands of sportsmen who fish abalone, less than one percent know all of the species they take; and, many engaged in the commercial fishery are not familiar with all the abalone they encounter. Since most of the laws and regulations governing the fishery are different for each species, proper identification is of the greatest importance for all concerned. In most instances the identity of an abalone can be determined by comparing it with written descriptions, shells or photographs of known species. Because of great variations in shell form, sculpture and

¹ Submitted for publication March 1960.

color, a number of abnormal and atypical individuals have been erroneously described as new. With few exceptions, descriptions of abalone have been confined to shell characteristics. Only rarely has the appearance of the living animal been mentioned. This report includes a brief description of the distinguishing parts of the body and epipodium of the live animal. These structures usually are characteristic for each species and have the added advantage of being easily recognized. In addition to presenting descriptive information and notes on distribution, habitat and economic importance, a brief outline of the general life history of abalone and a field key (Table 1) for the identification of the eight California species are included.

LIFE HISTORY NOTES

Abalone are marine gastropods, or snails, and are related to chitons, clams, oysters, squid, octopi and other mollusks. Of the 80,000 species of gastropods found throughout the world, more than half are marine, the rest being either air-breathing land species or fresh water inhabitants. Of the marine snails, the abalone is one of the most primitive in form and structure, and is related to stocks whose fossil forms are found throughout almost the entire geologic record. Fossils of modern abalone are found in rocks as old as the Oligocene of 30 to 35 million years ago. Abalone occur in the temperate and tropical seas of the world with the greatest number of different species, and perhaps the greatest number of individuals, off the coast of Australia. Although they occur among islands of the Central and South Pacific, their full range there is not known. They are found also off Japan, on the coast of China, among the Philippine Islands, along the Malay Archipelago, on islands of the Indian Ocean, in the Persian Gulf, and along the coasts of South Africa, West Africa, and the Canary Islands. In Europe they are taken from the English Channel Islands, the west coast of France and the Mediterranean Sea. A few abalone have been recovered from the tropical east coast of North America and several from the coast of Brazil. They are distributed along the west coast of North America from southernmost Baja California north into Alaska. No abalone have been reported from the Gulf of Mexico, Gulf of California, Central America, or the west coast of South America except at the Galapagos Islands. However, there are localities on the west coast of South America where water temperatures, currents, food

and habitat appear to be similar to other areas where abalone are found in abundance.

In abalone the sexes are separate and may be determined by forcing the foot and mantle away from the right side of the shell and inspecting the gonad. This is the large, smooth, curved, hornshaped organ which lies against, and bends partially around, the large muscle attaching the animal to the shell. In males the color of the gonad is cream or beige; in females, dark green.

California abalone spawn during spring and summer. Eggs and sperm are emitted into the water where fertilization takes place. The fertilized egg develops into a free-swimming larva which lasts one to two weeks. During the latter part of this stage a shell commences to form and as it gradually increases in size and weight, the young abalone sinks to the bottom. Here it adheres to rocks and in cracks or crevices where it begins to feed on minute algae growing on the substrate. The food is scraped off by the abalone's file-like tongue or radula.

Growth during the first few years is fairly regular. Most young abalone attain about an inch in length by the end of their first year and from three or four inches within four or five years. After the fifth year, growth is considerably slower. Some California species apparently never grow larger than six or seven inches, while others may reach 10 or 11.

Previous to the Department's investigation, it was thought that growth was constant and that the age of an abalone could be determined from the size of its shell. Recent findings have shown that growth is not constant, but usually varies from area to area for the same species and among different species within the same area.

Tagging experiments have shown that there is very little movement among abalone. Of those tagged and released in five to eight feet of water, 10 feet offshore, and collected up to four years later by shore fishermen, none had moved more than a few feet. Others tagged and released in deeper water 20 to 25 feet offshore, have never appeared on shore. When checked by the Department's divers a year later they were still in the same general area. Abalone tagged and released in 40 to 50 feet of water one-quarter mile offshore were still in the

area of release two years later. In the intertidal zone, red abalone (*Haliotis rufescens*) have moved over 100 yards parallel to shore but none has ever been observed to move from deep to shallow water.

Many of a group of approximately 800 red abalone transplanted from San Miguel Island to a shallow reef at Santa Catalina Island moved off the top of the reef into water 80 to 100 feet deep. It is believed that they were seeking water cooler than normally found at the top of the reef. A tagged abalone recovered at a depth of 20 feet by a skin diver had been originally taken in 20 to 25 feet of water and released in only five feet near shore. One tagged black abalone (*H. cracherodii*) remained in place on the same rock for two years.

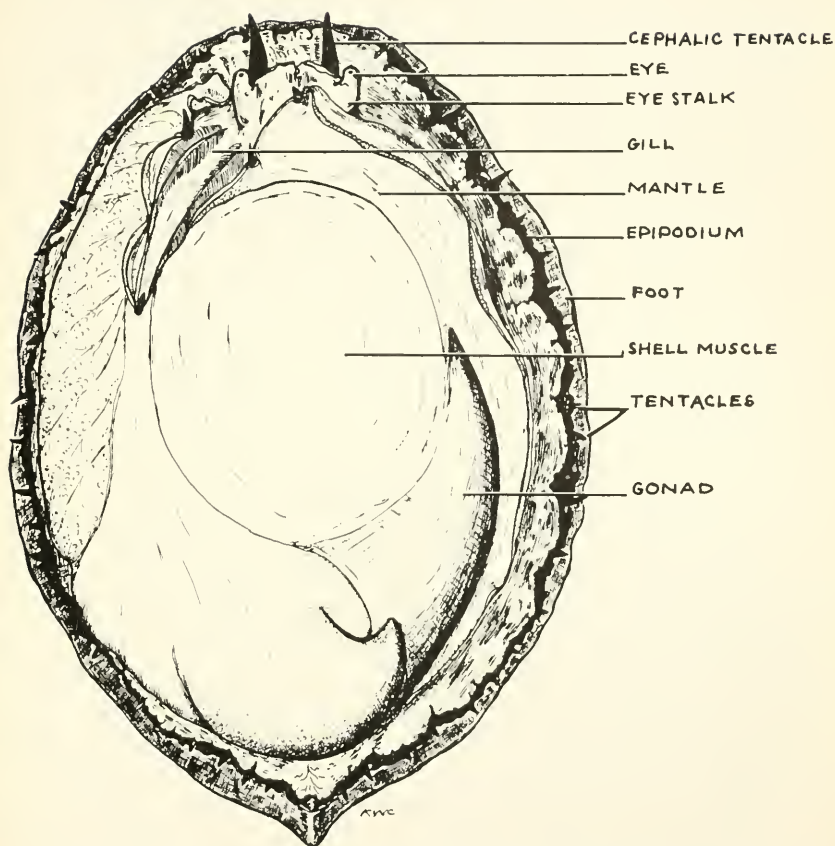


FIGURE 1. Dorsal view of abalone with shell removed showing prominent structures.

RED ABALONE

Haliotis rufescens Swainson 1822

Distinguishing Characters: This is the largest of all abalone, reaching over 11 inches in diameter. Outside color of shell dull brick red. Surface sculpture lumpy, usually covered with vegetation, barnacles, or other marine growth making color and sculpture difficult to determine. Inside iridescent and highly polished with large, distinctive, prominent, muscle scar having dark green markings. Muscle scar has a central "flow" area with smooth borders crossed by numerous paralleling fine lines. These lines are continuous across the anterior end of the muscle scar. Outer lip of shell extends over inner nacreous surface typically forming a narrow red rim (giving species its name); rim may be green, brown, blue, orange or mottled. Holes slightly raised, tubular, oval, usually three to four open, although specimens with no holes and others with more than four have been found. Body and epipodium are smooth, usually black, although some have alternate "dark" and "light" vertical stripes. Edges of epipodium scalloped, with black tentacles extending beyond edge of shell. In some individuals upper edge of epipodium is white and projects just beyond edge of shell.

Distribution: Sunset Bay, Oregon, to Turtle Bay, Baja California, and reported from the Farallons and all the Channel Islands. Over 800 were transplanted by the Department of Fish and Game in 1956 to Santa Catalina Island. In 1958, approximately 300 were transplanted to Washington where they were placed in the vicinity of the Strait of Juan de Fuca.

Habitat: Inhabits rock shores in certain areas along the coast from near high tide mark out to at least 540 feet, with maximum concentrations between 20 and 50 feet. In Northern California where it is not too plentiful, it is found near shore in shallower waters. It increases in abundance in central California and in the area from Cape San Martin to Morro Bay the greatest numbers are found. South of Point Conception it is only occasionally found along the shoreline and then in deeper water. These abalone apparently require an active surf. Usually they are not found in sheltered bays but prefer locations where there is considerable wave action and water exchange such as along rocky headlands and promontories.

Uses: The most important commercial abalone. Taken almost entirely from the San Simeon-Morro Bay area. The commercial catch of red abalone has averaged between 2.4 and 2.8 million pounds per year. Almost the entire product is processed fresh frozen and sold to restaurants. Some are sold in fresh fish markets where they bring from \$1.50 to \$2.75 per pound.

At one time there was a thriving market for the shells which were manufactured into jewelry, curios, etc., but the demand is not so great now, although from time to time this industry revives.

In northern and central California they are the principal abalone taken by skin divers and shore pickers. Along the coastline from Monterey to San Martin sea otters may be observed occasionally feeding on this species.

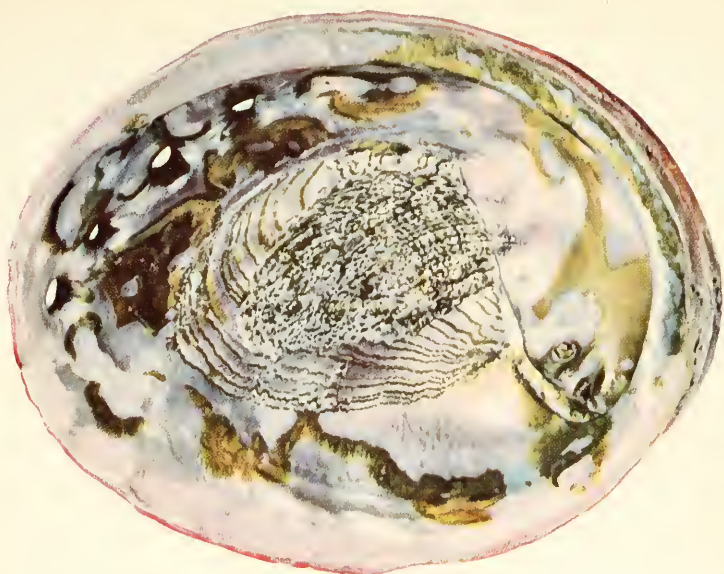
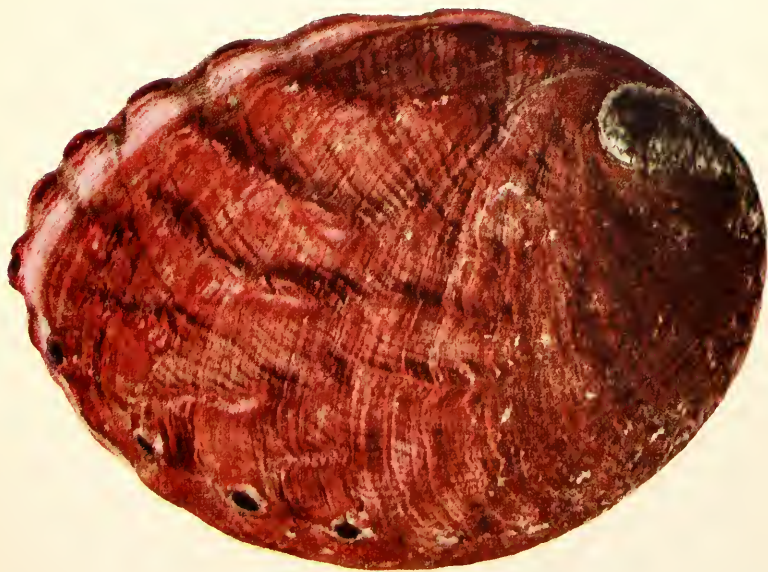


FIGURE 2. Red abalone, *Haliotis rufescens*, 8½ inches long from 6 fathoms off Pt. Estero, California, March 31, 1951. Photographs by Glen Bickford.



PINK ABALONE

Haliotis corrugata Gray 1828

Distinguishing Characters: Shell thick, circular and highly arched. Surface roughened with wavy corrugations (hence the name "*corrugata*"). Two to four large open holes bordered by sharply elevated rims, which may be worn flush with shell in some individuals. Edge of shell is usually sharply scalloped. Exterior of shell dull green to reddish brown, surface usually covered by heavy vegetation and other marine growth. Interior brilliantly iridescent, nacreous portion predominantly pink with traces of green. Large muscle scar with prominent dark green markings. Grows to 10 inches in diameter, but most are six to seven. Young specimens are quite flat until they reach three to four inches when shell begins to arch. This species offers a variety of shell forms making identification by shell characteristics alone sometimes difficult. The epipodium extending below the edge of the shell is roughened, its upper edge delicately lacelike in structure, is mottled black and white. The long, slender, black tentacles extend beyond the edge of the shell and the body is blackish.

Distribution: Pt. Conception south to Turtle Bay, Baja California. They are abundant on Santa Barbara and San Clemente Islands and have been found on all of the other Channel Islands except San Nicolas. Individuals of this species have been recovered from Cortez Bank and are also found at Guadalupe Island, Baja California.

Habitat: Along the rocky shores from the intertidal area out to 180 feet of water with major quantities located in the 20- to 80-foot depths. They are found in the more protected coves and bays as well as along the exposed coast in the active surf. They feed on giant kelp (*Macrocystis*) but will also eat other species of seaweed. The young remain under rocks and in cracks and crevices until attaining a size of three and one-half to four inches. They then move out and take up residence on the exposed surfaces of the rocks and cliffsides of the ocean bottom. Tagging experiments indicate that there is little movement. Tagged abalone have been recovered in the same general area in which they were released as much as three years later.

Uses: Since 1948 this species has supplied roughly one-half to two-thirds of the commercial abalone catch. Prior to 1942 they were not utilized to any extent by the fishery; but, during wartime, demands for extra protein made harvesting them profitable and the Channel Islands were reopened to commercial diving. Almost the entire commercial catch is taken from Santa Barbara, Santa Cruz, San Clemente, and Santa Catalina Islands, a small portion is taken along the mainland, primarily south of Pt. Conception in the Santa Barbara region.

In southern California this is the principal abalone taken by skin divers and sportsmen.

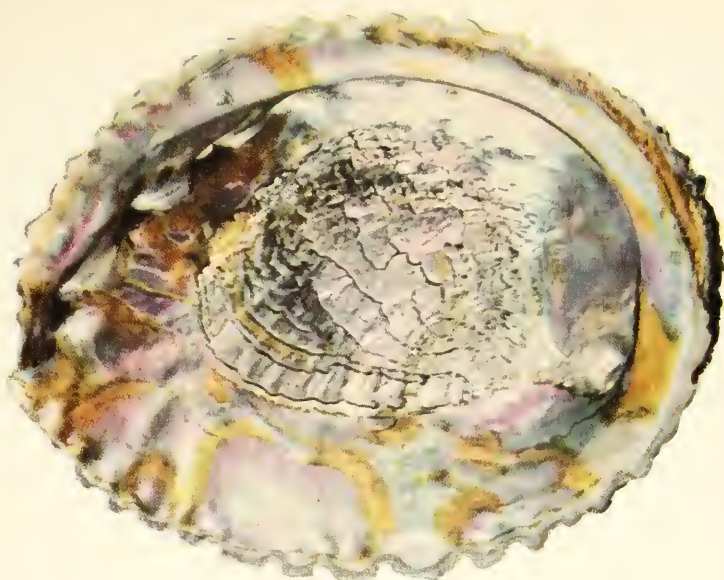


FIGURE 3. Pink abalone, *Haliotis corrugata*, 6 $\frac{5}{8}$ inches long from 10 fathoms off La Jolla, California, February 26, 1952. Photographs by Glen Bickford.



GREEN ABALONE

Haliotis fulgens Philippi 1845

Distinguishing Characters: Shell is oval, fairly thick, reaching 10 inches in greatest diameter but most individuals between five and eight. Outer surface an olive green to reddish brown color, regular in form and sculpture, with numerous, broad, flat-topped ribs separated by narrow, straight-sided grooves. The holes are small, circular, only slightly elevated (may be worn flush with shell in larger individuals) and five to seven are open. The shell may be covered by marine growths. The interior is brilliantly iridescent with predominant shades of dark green and blue. The muscle scar is vivid and striking in appearance. The interior is considered by many to be among the most beautiful of all abalone. The epipodium is an olive green with patches of brown. It is scalloped along the edge and small protuberances give it a rough, frilled surface. The tentacles are greyish green and somewhat short and thick and project from under the shell a short distance. This species shows considerable variation and *H. splendens* Reeve, *H. reevea* Bartsch, and *H. turveri* appear to be synonyms.

Distribution: Although reported from the Farallon Islands and from Monterey it is doubtful that the species is found so far north. Its northern range appears to be Pt. Conception and it extends south to Magdalena Bay, Baja California. This or a subspecies also is found at Guadalupe Island, Baja California. Records from the Gulf of California are based upon dead shells, probably carried there by travelers.

Habitat: This is a shallow water abalone inhabiting the rocky areas from about low tide out to 25 feet; occasional individuals are taken at from 50 to 60 feet but the great majority are located in 10- to 20-foot depths.

Uses: During the early days of the abalone industry it was the basis of the Japanese fishery in southern California and Mexico. They were very abundant among the Channel Islands during this time but rapidly disappeared under severe exploitation. At present they make up only a very minor portion of the commercial catch and are not much in demand by the industry. Skin divers and sportsmen take the majority of them. They frequently harbor a parasitic worm (*Echino pseudo-uncinatus*) that is unsightly and tends to discourage the commercial market for them.

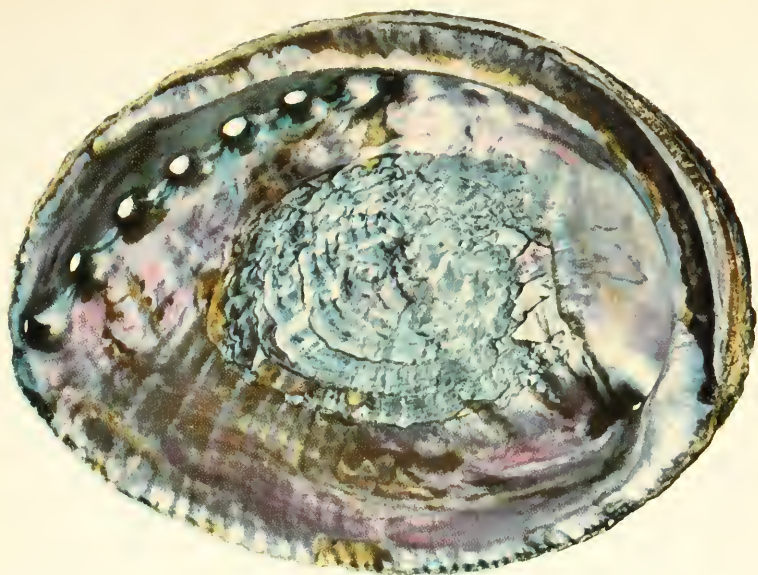
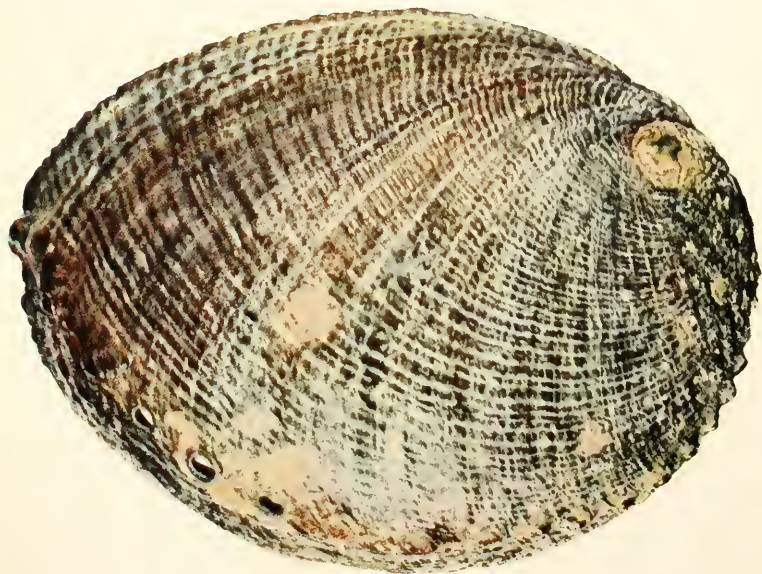


FIGURE 4. Green abalone, *Haliotis fulgens*, 7 inches long from 1 fathom off Long Point, Santa Catalina Island, February 22, 1952. Photographs by Glen Bickford.



BLACK ABALONE

Haliotis cracherodii Leach 1817

Distinguishing Characters: Color of outside shell typically dark blue or greenish black, sometimes orange. The exterior is usually quite smooth, with little or no marine growth on it. The inside is silvery with green and pink reflections, typically with no muscle scar. Shell deep, bluntly oval, although variations in shape and form are common. Reaches a diameter of eight inches but the majority are three to five. The outer edge of the shell projects over the inner nacreous surface forming a narrow dark blue, sometimes black or orange rim. Holes are flush with surface of shell and small in diameter; usually five to nine are open. Some shells may lack holes altogether (unnecessarily named *H. cracherodii holzneri* Hemphill, *H. c. imperforata* Dall, and *H. c. lusus* Finlay). (A subspecies found on Guadalupe Island, Baja California, *H. c. californiensis* Swainson, is characterized by 12 to 16 small open holes. *H. c. bonita* Orentt is the same as the Guadalupe Island subspecies). The body is smooth and black in color with small scallops along the upper edge of the epipodium; scattered short, slender, black tentacles protrude slightly beyond the edge of the shell.

Distribution: Coos Bay, Oregon, to Cape San Lucas, Baja California.

Habitat: From near high tide out to about 20 feet with the majority located intertidally. Usually found in great numbers crowded close together and at times stacked two or three on top of each other. This serves to keep shells free of marine growth since the intertidal area is sometimes lacking in sea weeds and they obtain food by grazing on each other's shells. They also capture broken bits of sea weeds which wash by.

Use: Of little importance to the commercial fishery because of darkness of meat and small size; utilized to some extent by lobster fishermen as bait. Although taken by sportsmen occasionally, not very desirable because of its small size and the dark color of the meat. In Baja California, Mexico they are canned whole and shipped to the Orient.



FIGURE 5. Black abalone, *Haliotis cracherodii*. Top: $3\frac{1}{2}$ inches long from intertidal zone, Catalina Harbor, Santa Catalina Island, California. Bottom: $3\frac{3}{8}$ inches long from intertidal zone, Catalina Harbor, Santa Catalina Island, California. Photographs by Glen Bickford.



FLAT ABALONE

Haliotis walallensis Stearns 1899

Distinguishing Characters: Ranging in size up to seven inches, but most individuals are three to five. Shell oval, long and narrow, considerably flattened. Exhibits less variation in shell form than other species. Color dark brick red with occasional mottlings of greenish blue and white. Holes four to eight, usually five or six open. Surface sculpture regular with numerous low, evenly rounded ribs crossed by closely spaced, lamellae-like striae. Inside of shell pale pink, with green reflections. No muscle scar although some may have small clumps of scattered green and brownish naere in the muscle attachment area. The body is a mottled yellow and brown with tinges of green. The epipodium is lacelike along the upper edge, colored a yellowish-green with large brown and yellow splotches. The surface of the epipodium is rough and the tentacles are dark green and slender.

Distribution: British Columbia to La Jolla, California, but rare south of Carmel, California. Generally not plentiful, but occasionally abundant in small areas.

Habitat: Found subtidally and to depths greater than 70 feet. Lives on and under rocks with other species of abalone, feeds by grazing on small attached algae.

Use: Not taken by commercial divers or sportsmen because of small size. In northern California whole shells are commonly found in the stomachs of cabezon (*Scorpaenichthys marmoratus*) which apparently remove them from the rocks and eat them whole.

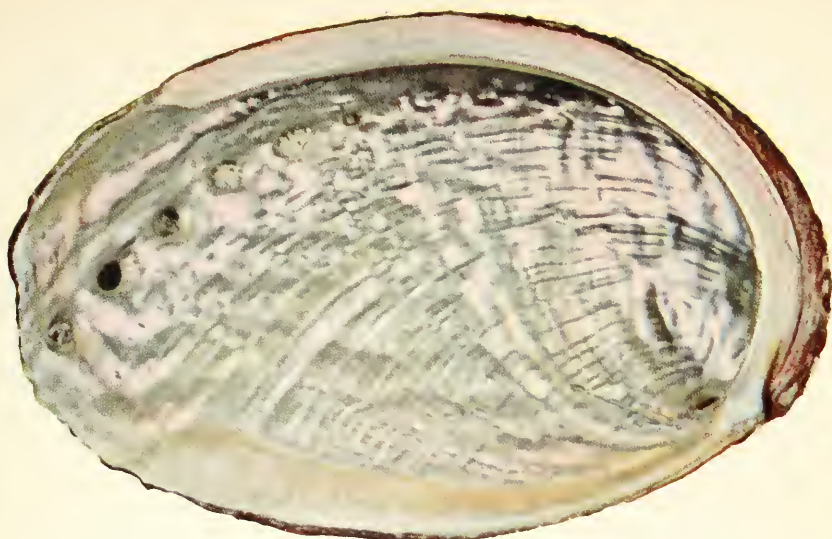
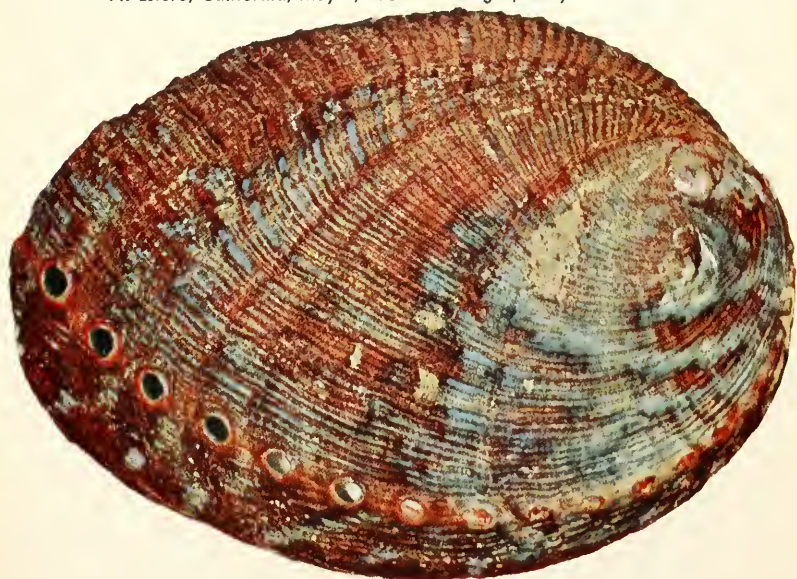


FIGURE 6. Flat abalone, *Haliotis walallensis*. Top: $3\frac{1}{4}$ inches long from 5 fathoms off Pt. Estero, California, April 30, 1956. Bottom: $3\frac{3}{4}$ inches long from 9 fathoms off Pt. Estero, California, May 1, 1956. Photographs by Glen Bickford.



PINTO ABALONE

Haliotis kamtschatkana Jonas 1845

Distinguishing Characters: This species exhibits considerable variation in shell form. In its northern range, which extends from Alaska south to Pt. Sur, California, it is characterized by a long, narrow, highly arched shell, having a rough, irregular surface. Larger individuals usually have a prominent spire. In its southern form, which extends from Pt. Sur to Pt. Conception, the shell is more oval in shape and not as highly arched; the surface is more regular and smooth and the spire is not as high. In both forms the shell is thin, colored a mottled greenish-brown with occasional white and blue scattered over the surface. Holes number from three to six, usually five, with raised edges and in some specimens a shallow, grooved channel under the line of holes parallel to the edge. The interior is an iridescent pearly white, typically with no marked muscle scar although larger individuals may have small clumps of greenish nacreous substance scattered inside the shell is the region of muscle attachment. Raised, lumpy areas of exterior are reflected by hollows and pit-like areas in the interior. Sizes range to six inches, but seldom exceed four. The epipodium is scalloped and lacelike along the upper edge and colored a mottled greenish-brown. The body is mottled tan and greenish brown; some with tinges of orange. The tentacles are green and slender, and the tips extend from under the edge of the shell when the animal is moving or feeding.

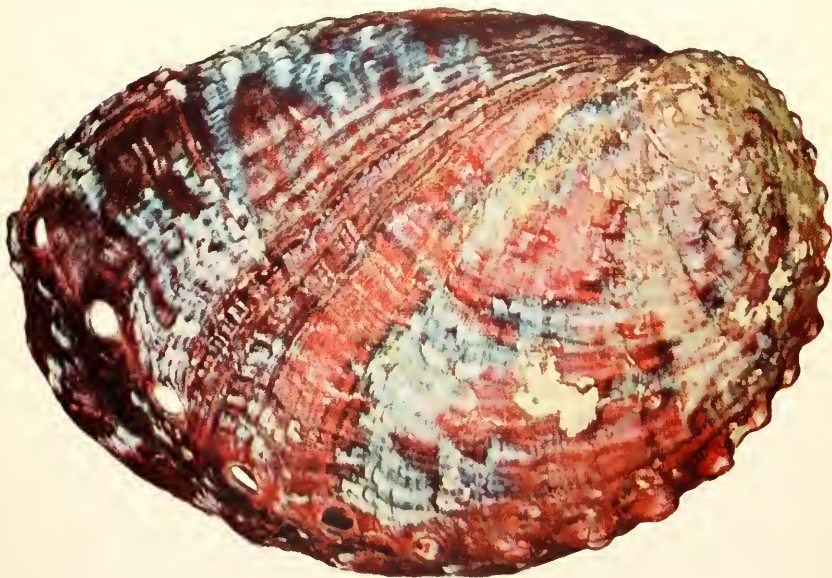
Distribution: Sitka, Alaska, to Pt. Conception, California. Formerly thought to extend to northern Japan via the Aleutian Island chain, but the Japanese form has been established as a distinct subspecies.

Habitat: In its northern range in Alaska it is found in shallow water among the rocks at low tide. Further south it is found in deeper water, and in central California the greatest numbers are found in the 35 to 50 foot depths. Although not a common species it is not rare and in some areas in deep water offshore may be found in large numbers. In deeper water this abalone is found more or less in the open on top of the substrate, rather than in cracks and crevices and on the underside of the rocks. The shells are covered with the same marine growths that are found on the substrate, making them difficult to distinguish from the surroundings. Food consists principally of smaller algae growing on the subsurface rather than the larger sea weeds which are favored by most of the other species. It is this diet which apparently gives the varied colors to the shell. *H. aulac* Bartsch 1940 and *H. smithsoni* Bartsch 1940 appear to be synonyms.

Uses: Not taken by commercial divers because of its small size. Taken only rarely by sportsmen. In Alaska a fishery is occasionally established for them but no extensive operations exist at this time.



FIGURE 7. Pinto abalone, *Haliotis kamtschatkana*. Top: $3\frac{3}{8}$ inches long from 8 fathoms off Pt. Estero, California, April 7, 1955. Bottom: $3\frac{1}{2}$ inches long from 5 fathoms off Pt. Estero, California, April 24, 1956. Photographs by Glen Bickford.



WHITE ABALONE

Haliotis sorenseni Bartsch 1940

Distinguishing Characters: Shell thin and light, oval, highly arched, reddish brown color exteriorly. Surface sculpture regular, with low spiral ribs, usually covered by lush marine growth, especially tube dwelling mollusks. The holes are highly elevated and between three and five are open. The interior is a striking pearly white with iridescent tints mainly pink; the outer edge of the lip is quite thin with a narrow red border. The muscle scar is typically absent, but if present is poorly differentiated; in some larger individuals small blue-colored naereous clumps are scattered over the interior. The epipodium is roughened and is mottled yellowish green and beige color. Its edges are scalloped and lacelike with occasional edgings of orange. The long, thin, light green and yellowish tentacles extend beyond edge of the shell. The portion of the mantle extending over the head region of the animal is edged in purple. The body is typically yellow or orange colored and the meat is quite tender. Shell attains a length of 10 inches, but most are five to eight. Individuals smaller than four inches are rare.

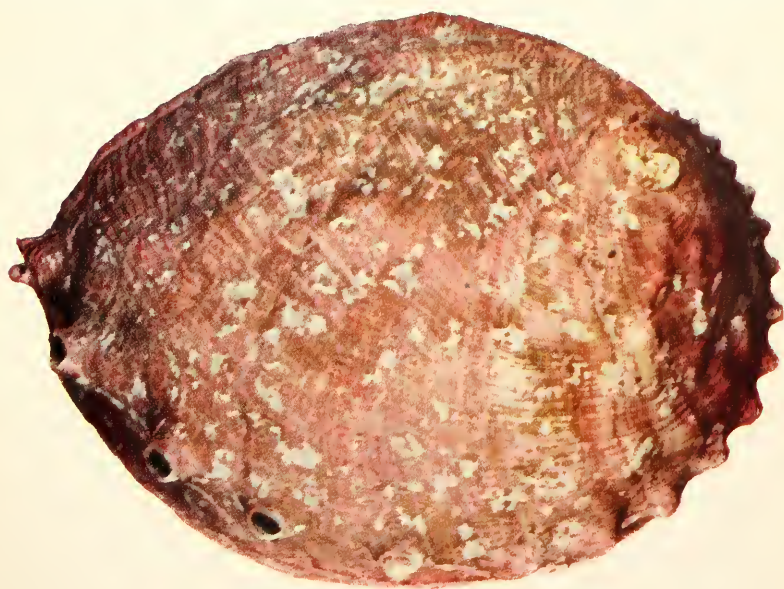
Distribution: Not found north of Pt. Conception, taken only occasionally along the mainland at Pt. Dume, Palos Verdes and San Diego. Most abundant among the Channel Islands of Santa Catalina, Santa Cruz, Santa Barbara, San Clemente and Los Coronados; also reported from Turtle Bay and Cedros Island, Baja California.

Habitat: A deep-water form found from 15 feet (rarely) to 150 (may extend to greater depths), with greatest concentration between 80 and 100 feet.

Uses: Not often taken because of the great depth at which it is found. Only recently has it appeared in the commercial catch where it is included with the pink abalone. The shells are quite beautiful when cleaned and polished.



FIGURE 8. White abalone, *Haliotis sorenseni*, $7\frac{3}{8}$ inches long from $16\frac{1}{2}$ fathoms on Harbor Reef, Santa Catalina Island, California, November 12, 1958. Photographs by Glen Bickford.



THREADED ABALONE

Haliotis assimilis Dall 1878

Distinguishing Characters: Shell oval, moderately thin, arched. Attains a length of six inches but most are smaller than four. Surface fairly regular with prominent, broad spiral ribs interspaced by several low, narrow ribs or ridges. Four to six holes open, small, tubular, raised. Shallow groove between holes and edge of shell. Spire moderately high. Surface of shell primarily greenish with patches and spots of dull brown, white, red or yellow. Outer lip of shell extends over inner nacreous surface, producing typical narrow reddish-brown and greenish colored border. Interior surface iridescent, light pearly white, no muscle scar in most individuals, occasional scar-like impression in larger specimens, some with small clumps of greenish nacre in vicinity of muscle attachment.

Body yellowish cream with brown blotching, epipodium light brown and cream, banded. Numerous small rounded protuberances on surface of epipodium, upper edge fringelike and flecked with white. Orange tinted on edge of foot and mantle, eye stalks and in throat region. Tentacles short and light brownish yellow in color.

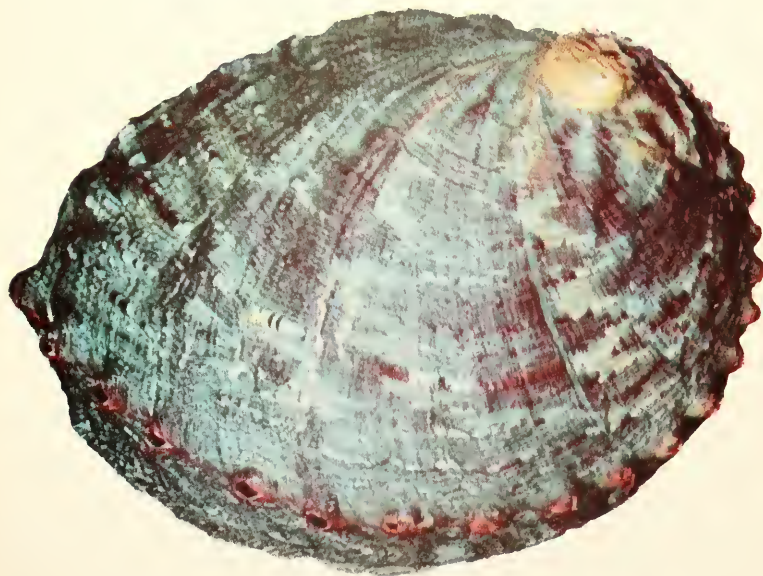
Distribution: From Pt. Conception south to Turtle Bay, Baja California, primarily along the mainland.

Habitat: Rocky bottoms offshore in depths ranging from 10 feet (rare) to over 120 feet; greatest numbers are found in 70- to 100-foot depths.

Uses: Seldom appearing in the commercial catch because of small size. Rarely taken by sportsmen. This species is perhaps the least common of all abalone found in California.



FIGURE 9. Threaded abalone, *Haliotis assimilis*, 5 inches long from 12 fathoms off Pt. Loma, California, June 1955. Photographs by Glen Bickford.



KEY TO THE ABALONE OF CALIFORNIA

There is no single character that will positively distinguish one abalone from another. Rather, identification is dependent upon a combination of characters including any or all of a number of items such as the color of the shell, the number of open holes, shell sculpture, body color, muscle scars, etc. These items and others are briefly described for each species in the key (Table 1). It should be kept in mind that while the descriptions are typical for the species, it is not uncommon for individuals of a given species to vary from one or more items listed in the key. These variations are discussed in the following terms used in key characters.

Terms Used in Key to Abalone of California

Number of Open Holes: For typical specimens, the number of open holes will fall within the ranges given in the key. However, individuals having more or fewer than the typical number listed for a given species are not uncommon.

Shape and Structure of Holes: The shape of the openings of the holes varies from circular to ellipsoid and range in diameter from approximately $\frac{1}{16}$ -inch to over $\frac{1}{2}$ -inch depending on the size of individual and the species.

The structures on which the holes are located vary in height from almost flush with the surface of the shell to chimney-like extensions projecting, in some species, over $\frac{1}{2}$ -inch from the surrounding surface.

Color of Exterior of Shell: Because most abalone support a considerable growth of marine organisms on the exterior of the shell, it may be necessary to remove some of this encrustation before the color can be determined. It should be kept in mind that color variations are not uncommon and in some species the intensity of the colors will be found to cover a relatively large range.

Shell Sculpture: The surface of the shell while characteristic for each species is subject to modification due to marine growths, wear, etc., and the sculpturing may be considerably masked. Two separate features, the general surface configuration and the spiral ribs or striations are indicated in the key for typical species. The surface configuration of some species is almost smooth while others are lumpy and irregular or with deep corrugations.

The spiral ribs or striations which run parallel to the holes are also characteristic for species; in some they are evenly rounded and smooth, in others they are coarse and roughened, and in still others they are in a pattern of various (irregular) widths.

Shell Margin: Inside of the shell will be found a colored rim running around the anterior or growing edge of the shell, usually more prominent near the holes. The color of this rim is the same as that on the surface of the shell. It will vary in width depending upon the species and upon the condition of the individual abalone. Older abalones usually have a narrow, rounded edge, while the young and growing specimens will have a wider, sharp-edged rim, usually scalloped.

Color of Body: This feature in combination with the color of the tentacles and the area between the tentacles is perhaps the most reliable and constant character for separation of the species. Body color tends to remain consistent for the majority of each species. Only minor deviations from those given in the key are encountered. The primary exception is found in the red abalone (*H. rufescens*) where occasional variations in color patterns and color shades are not unusual.

Color of Tentacles: The colors in the key are for the longest tentacles, and are usually similar to the major body color.

Area Between Tentacles: This area is part of the epipodium, which is the band- or collar-like structure arising from the dorsal part of the foot and stretching laterally from the head region around the posterior end of the body. The epipodial structures, other than the tentacles, are numerous and are pigmented black, brown, green, yellow, etc., depending on species. The top and the bottom edge of the epipodium has a scalloped or lacelike fringe cut by larger and smaller notches. The large tentacles in most species extend from the larger notches and appear more numerous on the upper edge. The area between the top and bottom edges of the epipodium ranges from smooth to roughened and is characteristically colored for each species.

Color of Muscle Scar: Only three species have a true muscle scar with a characteristic color and pattern. Among those species which do not have a true scar, small nacreous deposits are sometimes found in the muscle attachment region.

Interior of Shell, Major Iridescence: The interior of the shell of all abalones is iridescent but some species have a predominant color which gives a characteristic sheen or cast as indicated in the key.

Abalone species	Number of open holes	Shape and structure of holes	Color of exterior of shell	Shell sculpture	Shell margin	Color of body	Color of tentacles	Area between tentacles	Muscle scar	Characteristics of muscle scar	Interior of shell major iridescence
Red	3-4	oval, slightly tubular	dull brick-red	lumpy undulating	red rim	black	black	lobed, smooth	prominent	straight green lines at sides and front edge	dull green
Pink	2-4	round, highly elevated	dull green to reddish brown	irregular corrugated	mottled, sharp, scalloped	black	black	white lace-like edge	prominent	wavy bands and clusters of closely spaced "flow" lines with pinkish iridescence	pink
Black	5-9	round, small flush with shell	dark blue to black	smooth	blue or black smooth	black	black	lobed, smooth	absent	--	pearly white
Green	5-7	round, small slightly raised	olive green to reddish brown	regular with coarse spiral ribbing	brownish, sharp	olive green to light brown	olive green	green lace-like edge	prominent	same as for pink with green and blue iridescence	green and blue
White	3-5	oval, highly elevated	reddish brown	regular with low spiral ribbing	red, sharp	yellowish tan traces of orange	yellowish green	beige lace-like edge	absent	--	pearly white and pink
Pinto	3-6	oval raised	mottled greenish brown with white scattered white & blue	lumpy exterior reflected on interior by hollows, pits, etc.	narrow, mottled, scalloped	mottled greenish tan or brown	greenish brown	lace-like edge, greenish brown, rough	absent	--	pearly white
Flat	4-8	oval raised	brick red with white blue & green mottlings	numerous evenly rounded spiral ribs crossed by thin raised striations	thin, red	yellowish green mottled	yellowish green	lace-like edge, yellow-green roughened	absent	--	purplish pink
Threaded	3-6	oval slightly raised	mottled greenish with red, white or brownish spotting	widely separated prominent spiral ribs interspaced with numerous fine ribs	thin, mottled greenish, red-blue	yellowish cream and brown	brownish-yellow	lace-like edge, yellowish-brown roughened	absent	--	pearly white

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THE USE OF ANESTHETICS FOR THE HANDLING AND THE TRANSPORT OF FISHES¹

WILLIAM N. McFARLAND
Institute of Marine Science
The University of Texas, Port Aransas, Texas

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INTRODUCTION

The increased demands on fisheries resources in recent years has focused attention of fisheries biologists on a search for chemical compounds capable of improving various fish handling techniques such as tagging and marking, weighing and sexing, stripping, and particularly, transporting live fishes. Considerable effort has gone into a search for useful anesthetics and results indicate that several compounds are effective.

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In this investigation, several chemical agents capable of inducing anesthesia in fishes have been studied. Many show promise as anesthetics with wide application to fisheries work since they are capable of use on both fresh-water and marine fishes. The merits of these compounds for specific handling purposes will be evaluated. In addition, certain aspects of the process of anesthesia in fishes are stressed to indicate why anesthetics are beneficial to fisheries techniques. It is hoped such information will provide a basis for the development of improved fish handling techniques. Therefore, in the following section are reviewed some of the more important aspects of anesthesia in fishes.

Aspects of Anesthesia in Fishes Pertinent to Fisheries Work

The application of anesthetics to experimental and to fisheries work has often involved an element of expediency since anesthetics were used as a means to arrive at other desired ends. For this reason, little information has accumulated concerning the effects of these compounds on fishes. Recently, however, the process of anesthesia in fishes has been more fully described (McFarland, 1959a and b). Information from these studies pertinent to this paper is summarized below.

First, behavioral reactions of fishes, with only slight deviations, appear to be identical and to follow the same sequence (Table 1) when under the influence of diverse anesthetic agents. If allowance is made for differences in morphology, the sequential changes of behavior found for fishes during anesthesia are fundamentally similar to those found for higher vertebrates. This similarity indicates that anesthetically induced behavioral changes in fishes are the result of a step by step suppression of discrete central nervous centers.

Second, several findings relating to the type of drug and to the concentration used are of immediate importance to fisheries uses. In general, the narcotic potency or relative strength of an anesthetic increases as its molecular weight increases. Further, tolerance of fishes to anesthetics is rather low. Usually increasing the minimal dosage (considered as that concentration that induces only mild sedation during 12 hours, Table 1) by from 10- to 15-fold causes death. Specific depths of anesthesia can be controlled in fishes by careful manipulation of the concentration of anesthetic in the medium. For instance, specific stages of anesthesia (deep sedation, partial and total loss of equilibrium and loss of reflex reactivity) were maintained in killifish, *Fundulus parvipinnis*, and opaleye, *Girella nigricans*, for periods varying from 12 to 48 hours by using different dosages of most anesthetics, of which several are indicated in Table 2. The ability to induce a particular depth of anesthesia in a fish and to control it for long periods of time, without passing into a deeper level certainly is beneficial to fish handling techniques. However, under such conditions the tolerance of a fish to dosage becomes very narrow. With most of the anesthetics used, McFarland (1959a) found that an increase in concentration by from 1.5- to 2.0-fold increased the depth of anesthesia by one level (Table 1).

The demonstration of a similarity of behavioral responses in different species of anesthetized fishes, of the induction of the same behavioral reactions with diverse drugs, the inference that anesthesia in fishes is the result of sequential suppression of the central nervous system, that anesthesia in fishes closely parallels the process in higher vertebrates,

the fact that given depths of anesthesia can be controlled for long periods of time and that the dosage of a particular anesthetic is related to its molecular weight, all lend a new degree of predictability to the use of anesthetics on fishes for fisheries problems.

In general, when employing anesthetics, most fish handling techniques will require the induction of either of two major but distinct physiologic states (bold face type, Table 1). For instance, in tagging, marking and weighing of fishes, immobility is requisite to efficiency and success. In contrast, when using anesthetics in transporting fishes induction of sedation is the primary requisite to success. Therefore, the use of anesthetics in fisheries work can be considered under two divisions, viz.: operative procedures and transport procedures. For practical reasons each of these will be considered separately. Individuals interested in using anesthetics only in transporting fishes need refer solely to the section on fish transport, while individuals interested in their use only for operational procedures can refer to the following section.

THE USE OF ANESTHETICS FOR OPERATIVE PROCEDURES

Anesthetics have been used on fishes for experimental operations and for microscopic examination in experimental investigations, and in fisheries work for weighing, measuring, stripping and spawning, fin clipping and marking, and general handling. Many different methods have been used to produce anesthesia. Several workers have immersed fish in cracked ice or ice water (Abramowitz, 1937; Parker, 1937, 1939; Abramowitz, *et al.*, 1940; Osborn, 1938, 1941) while Haskell (1940a) produced a paralysis lasting about two minutes with electric shock. Whether the 'sleep' induced by such methods is similar to that induced with chemicals during anesthesia is problematical, but the disadvantage of such methods (severe stress) has been indicated by Pickford and Atz (1957).

Most workers, however, have avoided drastic techniques and have preferred to use anesthetics that are easily dissolved in a solvent. Ether has been used successfully at concentrations of one to five percent by Foster (1941), Griffiths, *et al.*, (1941), Vivien (1941), Eshmeyer (1953), Nelson (1953) and Allison (1954). Ether is effective, but has the disadvantage of being highly volatile and inflammable. Of water soluble narcotics, probably urethane has been most widely employed as a general anesthetic for animal experimentation. Young (1935), Hogben (1936), Waring (1940), Hasler and Meyer (1942), Gerking (1949) and Johnson (1954) have used urethane on fishes to produce immobility at concentrations ranging from 0.5 to 4.0 percent. Recently, the carcinogenic activity of this anesthetic has been reviewed by Wood (1956), and he suggests that its continued use might be a hazard to the worker.

Burrows (1952) and Nelson (1953) have reported that chlorobutanol causes complete anesthesia (immobility) in two to three minutes at concentrations from 2.8 to 3.5 mM/L in several salmonids. Nelson found that methane tricainesulfonate, henceforth referred to as M.S. 222, rapidly induced complete anesthesia at a concentration of 0.34 mM/L but caused 100 percent mortality at a slightly higher concentration (0.4 mM/L). Pickford (1953) has employed M.S. 222 at 0.13 mM/L to completely anesthetize *Fundulus heteroclitus* and feels that it is superior to ether, especially for smaller teleosts (Pickford and Atz,

1957). Gilbert and Wood (1957) have rather spectacularly used this anesthetic for quieting large elasmobranchs. They sprayed or poured a concentrated solution of M.S. 222 (4 mM/l.) directly on the gills and in this manner were able to handle sharks as large as 400 pounds with ease.

Depth of Anesthesia, Effective Concentrations and Valuable Anesthetics for Operational Procedures

The loss of motility and muscle tone during total loss of equilibrium and loss of reflex reactivity (Table 1) make these stages desirable for operations, marking and tagging and the handling of fishes since both produce immobility. In these stages of anesthesia fishes can be removed from the water for periods in excess of five minutes without ill effects and often longer if care is taken to control temperature and to keep the gills moist. If it is desired to maintain deep anesthesia for long periods, concentrations slightly below the fatal dosages are useful. Such dosages are especially useful where hundreds of fish are to be marked or tagged. With these concentrations the fish can be left in the anesthetic solutions for periods as long as 12 hours without fatalities. Approximate concen-

TABLE 1

Classification of the Behavioral Changes That Occur in Fishes During Anesthesia

(Levels of anesthesia considered valuable to fisheries work are in bold face type)

Definable levels of anesthesia			Behavioral responses of fish
Stage	Plane	Word equivalents	
0		Normal	Reactive to external stimuli, equilibrium and muscle tone normal
I	— 1	Light sedation	Slight loss reactivity to external stimuli (visual and tactile)
I	— 2	Deep sedation	Total loss reactivity to external stimuli except strong pressure, slight decrease opercular rate
II	— 1	Partial loss equilibrium	Partial loss muscle tone, react only to very strong tactile and vibrational stimuli, rheotaxis present, but swimming capabilities seriously disrupted, increase opercular rate
II	— 2	Total loss equilibrium	Total loss muscle tone, react only to deep pressure stimuli, decrease opercular rate below normal
III		Loss of reflex reactivity	Total loss of reactivity, respiratory rate very slow, heart rate slow
IV		Medullary collapse	Respiratory movements cease, followed several minutes later by cardiac arrest

tration ranges for several anesthetics are indicated in Table 2. Slight changes in these dosages should compensate for differences in the depth of anesthesia as affected by temperature and size of fish (McFarland, 1959b). Familiarity with the sequence of anesthesia and the behavioral characteristics of each level (see McFarland, 1959b, for detailed description) should reduce the hazard from overdosage since at all times the actual depth of anesthesia can be visually determined.

Often, the time required to induce deep anesthesia at the concentrations indicated in Table 2 is in excess of one hour. When it is desired to induce deep anesthesia rapidly, as when tagging large fishes, concentrations in excess of those indicated can be used provided the fish are removed from the anesthetic, or, the solution diluted, as soon as the desired degree of anesthesia has been induced. Under these circumstances deep anesthesia can be induced without ill effects in less than 10 minutes. Most of the anesthetics indicated (Table 2) are useful, but M.S. 222 has the advantage that it rapidly induces a deep anesthesia from which recovery is extremely fast. Tertiary amyl alcohol and methyparafynol (= Dormison) are also effective in that they induce rapid anesthesia and can be dispensed easily in liquid form.

TABLE 2

Approximate Concentrations Necessary to Induce Deep Anesthesia in *Fundulus parvipinnis*
During a Four-hour Period with Different Anesthetics

(Anesthetics considered most desirable for inducing deep anesthesia are indicated in bold face type. Slight increase or decrease in dosage should allow induction of deep anesthesia in most species of fishes.¹ Dosages are given in milliliters or in grams per gallon of water.)

Anesthetic	Level of anesthesia ²	
	Total loss of equilibrium	Total loss of reflex reactivity
Ethyl alcohol	---- ³	---- ³
Tertiary butyl alcohol	---- ⁴	= 30 ml.
Urethane	10-13 gms.	13- 2 gms.
Chloral hydrate	8.5-9.0 gms.	9.0-11.5 gms.
Tertiary amyl alcohol	4-5 ml.	6-7 ml.
Methylparafynol (= Dormison)	2.0-3.5 ml.	3.5-4.5 ml.
Sodium amytal (salt water)	0.4 gms.	0.15-0.65 gms.
Sodium amytal (fresh water)	0.2-0.26 gms.	0.26-0.33 gms.
Chlorobutanol	0.02-0.025 gms.	0.03-0.04 gms.
Methane tricainesulfonate (= M.S. 222)	0.02-0.025 gms.	0.025-0.030 gms.
Tribromoethanol	0.015-0.02 gms.	0.02-0.025 gms.

¹ Due allowance must be made for temperature and size of fish.

² See Table 1.

³ Anesthesia not controllable.

⁴ Anesthesia not effectively controlled.

Recovery and Long-term Effects of Anesthesia

Specific experiments to determine recovery rates with different anesthetics and from different depths of anesthesia were not performed in this investigation. However, groups in different stages of anesthesia were randomly removed during dosage experiments from various anesthetic solutions after different lengths of exposure and the recovery rates recorded (Table 3). Fish always recovered when the depth of anesthesia had not exceeded the level of loss of reflex reactivity.

In six experiments in which medullary collapse (Stage IV, Table 1) was induced, but not prolonged over two to three minutes, recovery was complete in all but one fish. Also, recovery from deep sedation (Stage I-2, Table 1) was complete in 30 minutes or less regardless of anesthetic or exposure time. Recovery from deeper levels of anesthesia appears to be related to the anesthetic, the concentration used and the length of exposure. For instance, specimens of *Fundulus parvipinnis* exposed to chlorobutanol at 5 and 10 grains/gallon reached Stage II-2 (total loss of equilibrium) at 90 and 20 minutes respectively, and were removed. Recovery was complete or nearly so in both groups at the same time (100 minutes). In contrast, *Girella nigricans* exposed to the same anesthetic at 20 and 50 grains/gallon for two minutes, were in Stage IV (medullary collapse). Complete recovery was attained in 51 minutes by the former group, but not until 76 minutes for the later group. These findings are in agreement with those of Muench (1958), who found recovery time in fish exposed to quinaldine to be proportional to the length of exposure and to the concentration of the anesthetic.

TABLE 3
Recovery from Anesthesia as Determined from Dosage Experiments

Anesthetic	Fish	Concentration per gal.	Exposure time	Anesthetic stage attained ¹	Recovery	
					Stage	Time, min.
Methylparafynol	<i>Fundulus</i>	1.5 ml.	12 hrs.	I-2	0	30
	<i>Fundulus</i>	3.5 ml.	12 hrs.	III	I-2	30
	<i>Fundulus</i>	3.5 ml.	12 hrs.	III	0	60
Tert. amyl alcohol	<i>Girella</i>	3.8 ml.	3 hrs.	III	0	20
	<i>Girella</i>	40 ml.	1 min.	IV	0	20
Chlorobutanol	<i>Girella</i>	5 grs.	35 min.	III	0	55
	<i>Girella</i>	10 grs.	15 min.	IV	0	95
	<i>Girella</i>	20 grs.	2 min.	IV	0	51
	<i>Girella</i>	50 grs.	2 min.	IV	0	76
	<i>Fundulus</i>	1 gr.	12 hrs.	I-2	0	15
	<i>Fundulus</i>	5 grs.	90 min.	II-2	I-1	100
	<i>Fundulus</i>	10 grs.	20 min.	II-2	0	100
M.S. 222	<i>Girella</i>	5 grs.	10 min.	IV	0	10
	<i>Fundulus</i>	5 grs.	12 min.	III	0	13
Urethane	<i>Girella</i>	150 grs.	70 min.	II-2	0	80
	<i>Girella</i>	200 grs.	60 min.	IV	0	120
	<i>Fundulus</i>	150 grs.	24 hrs.	II-2	II-1	60
	<i>Fundulus</i>	150 grs.	24 hrs.	II-2	0	180

¹ See Table 1.

Subsequent recovery was also observed in larger and more active fishes that had been anesthetized. Several albacore, *Thunnus germon*, were anesthetized in attempts to transport them to Marineland of the Pacific in September, 1956. Sedation (Stages I-1 and I-2, Table 1) was induced and maintained for one to two hours with tertiary amyl alcohol at a concentration of 2.0 ml./gal. Profuse bleeding from the cutaneous blood sinns, caused when the albacore scraped the sides of the tank, clouded the water and necessitated introduction of fresh sea water. However, lightly anesthetized albacore were observed to swim more

slowly than previously observed non-anesthetized specimens. Deeper anesthesia was induced (Stages II-2 and III, Table 1) by immersing them in a plastic sac containing tertiary amyl alcohol at higher concentrations (10 to 15 ml./gal.). Induction of total loss of equilibrium and loss of reflex reactivity occurred in one to three minutes. In this condition albacore were limp and could be easily handled. When placed in the transport tank recovery of equilibrium was rapid and they began to swim within five minutes. Compared to non-anesthetized albacore, they initially swam more slowly and tended not to hit the sides of the tank. However, after complete recovery they were no better adjusted to confinement than non-anesthetized albacore. Whether continual mild sedation would have increased the success of confinement is unknown.

Peculiarities were noted by A. W. Ebeling (personal communication) in the recovery of Pacific mackerel, *Pneumatophorus diego*, that had been anesthetized in tertiary amyl alcohol. At a concentration of 0.3 percent tertiary amyl alcohol, the mackerel became moribund after four minutes exposure. Concentrations of 0.4 percent induced this condition in two to three minutes. Judging from his description, the fishes were in Stage II-2 to III (Table 1). Of 14 specimens, the only one that did not recover was anesthetized for five to six minutes after reaching Stage II-2 to III. He reported that the mackerel regained equilibrium and swam within 5 to 15 minutes. Schooling behavior was not normal, however, until 30 minutes had elapsed. The anesthetized fish showed difficulty in maintaining a constant position in the school to which they were returned. In view of similar findings of rapid recovery of equilibrium in *Girella* and *Fundulus*, but with prolonged delays in deep sedation the schooling idiosyncrasy noted by Ebeling was probably due to a persistence of sedation.

Further information on recovery from anesthesia was obtained from the experience of Kenneth S. Norris and John Prescott, who made use of the author's findings in deeply anesthetizing opaleyes for operations. The following results were obtained during the first quarter of 1958. Six opaleyes, ranging from 600 to 1,300 gms., were anesthetized 27 separate times. The types of anesthetics, concentrations, and frequencies of use were: M.S. 222, 2.0-2.5 grs./gal., five inductions at three-day intervals; methylparafynol, 3.5 ml./gal., four inductions at three-day intervals; and tertiary amyl alcohol, 4.5-5.0 ml./gal., 17 inductions at from two- to three-day intervals. The author was present on several occasions and evaluated the rates and the depths of anesthesia induced. Total loss of equilibrium (Stage II-2) and loss of reflex reactivity (Stage III) were induced within 8 to 12 minutes and were typical of that described for smaller opaleyes (four to eight gms.). Reactivity did not return for 20 to 30 minutes. The six opaleyes were still alive and normal on June 15, 1958.

No long-term effects have been noted in recovered fishes. The most detailed check may be recounted. Nineteen specimens of opaleye and 29 of the wooly sculpin, *Clinocottus analis*, were collected with methylparafynol from a tide-pool at Palos Verdes, California. The fish were in deep sedation and partial loss of equilibrium when removed from the pool to untreated sea water. They were weighed and kept in an aquarium for 21 days, at which time, after daily feeding they were reweighed. The total gain in weight for the entire group was 10.1 per-

cent of the original weight. For *Girella* it was 11.5 percent and for *Clinocottus* 9.3 percent. Both species appeared normal at all times and, in addition, eggs of *Clinocottus* were found deposited on the rocks of the aquarium. Anesthesia caused no apparent after effects.

From the information gathered, recovery of several species of fishes from anesthesia after one or many exposures appears to be complete and without demonstrable long-term effects. This agrees with the findings of Witjens, *et al.* (1947) and Muench (1956, 1958). Fish anesthetized with M.S. 222 had the fastest recovery rate. Recovery from tertiary amyl alcohol and methylparafynol, although not as rapid, is fast (Table 3) while recovery from urethane is slow.

THE USE OF ANESTHETICS FOR THE TRANSPORTATION OF FISHES

The first worker to recognize the potential use of anesthetics for transporting fishes appears to have been Aitken (1936). Little further work was done until Reese (1953) and Calhoun (1953) reported sodium amytal to be effective in approximately doubling the weight of trout normally transported. Following this lead, the California State Department of Fish and Game and other fisheries agencies began to employ sodium amytal on a larger scale in the transport of trout. Until quite recently, however, information on the use of anesthetics for fish transport unfortunately had not found its way into the literature.

The only clear experimental demonstration of the value of anesthesia in transporting fishes is that of Nemoto (1957) who indicated sodium amytal caused a one-third reduction in the rate of oxygen consumption of the cichlid, *Tilapia mossambica*, sealed in containers. Phillips and Brockway (1954) were able to demonstrate reductions in the rates of excretion and of oxygen consumption of brooktrout, *Salvelinus fontinalis*, using sodium amytal, but their results are not easy to interpret (see McFarland, 1959a). The need for more fundamental data on the effects of anesthetics on fishes for transport purposes is indicated by the results of Webb (1958) who used M.S. 222 as an aid to increase the loads of bluegills carried. He states that, "Though some extremely heavy loads were hauled, the most successful tests could not be duplicated and at times the control fish seemed to haul as well as or better than the drugged ones."

It has been indicated that deep sedation suppresses reactivity of fish to external stimuli without upsetting equilibrium (see Table 1). This level of anesthesia also has been demonstrated to reduce the oxygen consumption of individuals to basal rates (McFarland, 1959b).

Of the levels of anesthesia described (Table 1) deep sedation would seem most desirable when transporting fishes. Deeper anesthesia, like partial loss and total loss of equilibrium, is considered undesirable since it would result either in an involuntary increase in movements or the descent of the fish to the tank bottom, where, during transport, they would be crowded dangerously. The success reported by Reese (1953) and Calhoun (1953) in transporting trout with sodium amytal is best attributed to the induction of sedation and the consequent decrease in activity metabolism. In fact, Reese suggested that sodium amytal was probably beneficial in trout transport in that it might reduce the activity of fishes and result in a slowing of their body functions and oxygen requirements.

Although practical results are encouraging, adequate experimental demonstrations of the benefits of anesthesia for the transport of fishes have as yet not been presented. The experiments described in the following section were designed to test both the utility of anesthetics and of sedation for transporting fishes.

Laboratory Experiments Testing the Utility of Anesthesia for Prolonging the Time to Mortality

Experimental Assumptions

Groups of fish were sealed in vessels under controlled conditions and allowed to reduce the oxygen tension to a lethal level. Under such conditions it seems reasonable to assume that, if oxygen proved limiting, differences in the time to 50 percent mortality (used as an endpoint) between anesthetized (Stage I-2) and non-anesthetized groups should reflect differences in metabolism, a result generally considered of value in fish transport (Reese, 1953; Osborn, 1951; see also section on Anesthesia and Control of Excess Activity). Therefore, valuable anesthetics should cause increases in the time to mortality, if they cause a decrease in metabolism.

Also, stimulated groups should die before non-stimulated groups, since their metabolism would be increased. When stimulated, anesthetized groups of fish sealed in vessels should show smaller decreases in the time to mortality than non-anesthetized groups. Comparisons of the time to mortality in anesthetized and control groups, both stimulated and non-stimulated, should allow evaluation of anesthesia for transporting fishes. This latter type of experiment best approximates actual transport conditions since crowding, sloshing, vibration and other such "non-discriminative stress" (Brett, 1958) are typical of usual transport operations. Such experiments henceforth will be termed closed-system mortality experiments.

Apparatus and Methods

Fundulus parvipinnis and *Girrella nigricans* were used. All *Fundulus* were obtained with a beach seine from a sandy point and a slough in south San Diego Bay, San Diego County, California. *Girrella* were obtained from an intertidal reef at Portuguese Bend, Los Angeles County, California. The sizes of individual fish used varied from 34.5 mm (0.75 gms.) to 73.0 mm (11.6 gms.) standard length for *Girrella*; and from 31.5 mm (0.52 gms.) to 77.5 mm (12.5 gms.) standard length for *Fundulus*.

Both species were held in 20 degree C. copper treated sea water (0.10 p.p.m. copper) for two weeks prior to temperature acclimation. This treatment was beneficial in healing skin and fin damage caused in capture and in the removal of ectoparasites. Fish were fed chopped mackerel and shrimp four times a week, but feeding was discontinued 24 hours prior to experiments. Captive *Girrella* thrived under this treatment as did *Fundulus*, but a small proportion (about 20 percent) of the latter died, apparently from starvation. The cause of this mortality was not determined. It was not alleviated by providing excess amounts of food. The fish in poor nutritional states were not used in experiments.

After two weeks in copper treated sea water, groups of *Fundulus* were acclimated to temperatures of approximately 20 and 27 degrees C. for a period in excess of two weeks prior to use. Maximum temperature variations were from 18 to 21 degrees C. and from 24 to 27.3 degrees C. for each group. Groups of *Girella* were acclimated for a period of at least two weeks in sea water of the prevailing ocean temperature. During this period temperature varied from a low of 14.6 degrees to a high of 18.8 degrees C.

Six, widemouth one-gallon jars with screwtop lids were used as experimental chambers in which to seal groups of fish. During experiments, all jars were placed in separate compartments in a long, glass aquarium. The aquarium, supplied with sea water in which the groups of fish were acclimated, served as a temperature control. A constant overhead light source was used and visual cueing eliminated by placing a viewing port opposite each vessel.

The anesthetic was added (enough to induce and maintain Stage I-2) and the sea water aerated in large 15-gallon tanks to assure homogeneity, one hour prior to each experiment. A water sample was drawn from each vessel before introducing a group of fish and again at the time of 50 percent mortality.

Several variables were either measured or controlled during the course of the experiments. They were:

(a) Size and number of fish. Fish were separated into size groups to allow for the regression between weight and oxygen consumption.

(b) Oxygen. Dissolved oxygen was measured at the beginning and conclusion of all experiments by the Alsterberg modification of the Winkler method (Standard Methods, 1955, p. 255). The titration error, determined with replicate samples, was 1.66 percent.

(c) pH, alkalinity and carbon dioxide. Hydrogen ion concentration was measured at the beginning and conclusion of each experiment with a Beckman Model N portable pH meter. Alkalinity was determined by acid titration of 50 ml. samples to a pH of 4.5 (Sverdrup, *et al.*, 1942, p. 195; Theroux, *et al.*, 1943; Standard Methods, 1955, pp. 35-38). The mean error of titration based on replicate samples was 1.8 percent. Carbon dioxide was measured indirectly with nomographs relating pH, alkalinity and total salt content to free CO₂ (Moore, 1939; Standard Methods, 1955, p. 57). The method is subject to error, but relative and large changes in CO₂ are detectable (McFarland and Norris, 1958).

(d) Waste products. During several experiments, inorganic and organic nitrogen were measured to determine if levels were high enough to cause mortality. A modification of the Kjeldahl method employed by Robinson and Wirth (1934) was used.

Several interacting variables can cause mortality of fishes in limited volumes of water when aeration is not supplied. Oxygen deficiency and carbon-dioxide excess are major limiting factors that act rapidly (McFarland and Norris, 1958). Results from the closed-system mortality experiments showed that oxygen deficiency and not CO₂ was the limiting factor. In these experiments, the initial oxygen content of the water varied from a low of 2.95 ml./L to a high of 5.16 ml./L. Since the time to 50 percent mortality is related to available dissolved oxygen a correc-

tion factor, based on the experimental demonstration that oxygen depletion by the groups was a linear function of time and independent of the oxygen tension of the water above 0.5 ml. O_2/L , was applied to all the data. Differences in the time to 50 percent mortality between experimental groups, after correction for initial oxygen content, could be accounted for by differences in the mean size of the groups, and therefore their metabolic rates. Results were consequently plotted against mean size of the groups to account for differences in metabolism due to size.

Results From Mortality Experiments

The effects of four anesthetics (tertiary amyl alcohol, methylparafynol, M.S. 222 and chlorobutanol) on the time to 50 percent mortality of groups of opaleye were investigated. The regression of time to 50 percent mortality on mean weight for anesthetized and non-anesthetized groups was a straight line when plotted on log-log paper (Figure 1). Correlation values of -0.95 and -0.97 for anesthetized and control groups, respectively, indicate the linearity of the data. Covariance analysis of the several groups indicated the means and slopes of each group were not significantly different and that one regression line would fit all the data. Since significant differences were not found between the anesthetized groups, the data have been pooled. Covariance analysis of the anesthetized and control groups revealed that a significant difference existed between the means ($p < 1$ percent) and that one regression line would not fit all the data. No difference was found, however, between the slopes of each group. Anesthetized groups tended to live longer than controls (Figure 1). Comparison of the alpha coefficients of the two regression lines (see legend, Figure 1) allowed this tendency to be estimated. Division of the coefficients ($9.94/8.82 \times 100$) showed that the anesthetized groups lived on the average 12 to 13 percent longer.

These slight increases in the time to mortality of the anesthetized fish are considered the result of a decreased metabolism resulting from the loss of reactivity that accompanies Stages I-1 and I-2. Since stimulation was not applied during these experiments, large differences in times of mortality were not expected. However, when stimulation was used on groups of *Girella* no differences, from those graphed in Figure 1, were revealed. This is in contrast to similar experiments on *Fundulus*. The absence of differences is presumed the result of the stimulus used since, apparently, it did not increase activity sufficiently to modify the time to 50 percent mortality.

Closed-system mortality experiments performed on groups of *Fundulus* as indicated earlier, were performed at two ranges of acclimation temperatures (18 to 21 degrees and 24 to 27 degrees C.). Results were graphed on log-log paper, as for *Girella*, in Figure 2 (18 to 21 degrees C. groups) and in Figure 3 (24 to 27 degrees C. groups). The relation between time to 50 percent mortality and weight represents a straight line (correlation from -0.84 to -0.99). Groups of *Fundulus* at the lower temperature (Figure 2) were pretreated for one hour with tertiary amyl alcohol, methylparafynol, M.S. 222 or chlorobutanol while groups at the higher temperature (Figure 3) were pretreated with tertiary amyl alcohol, methylparafynol and M.S. 222. All groups were

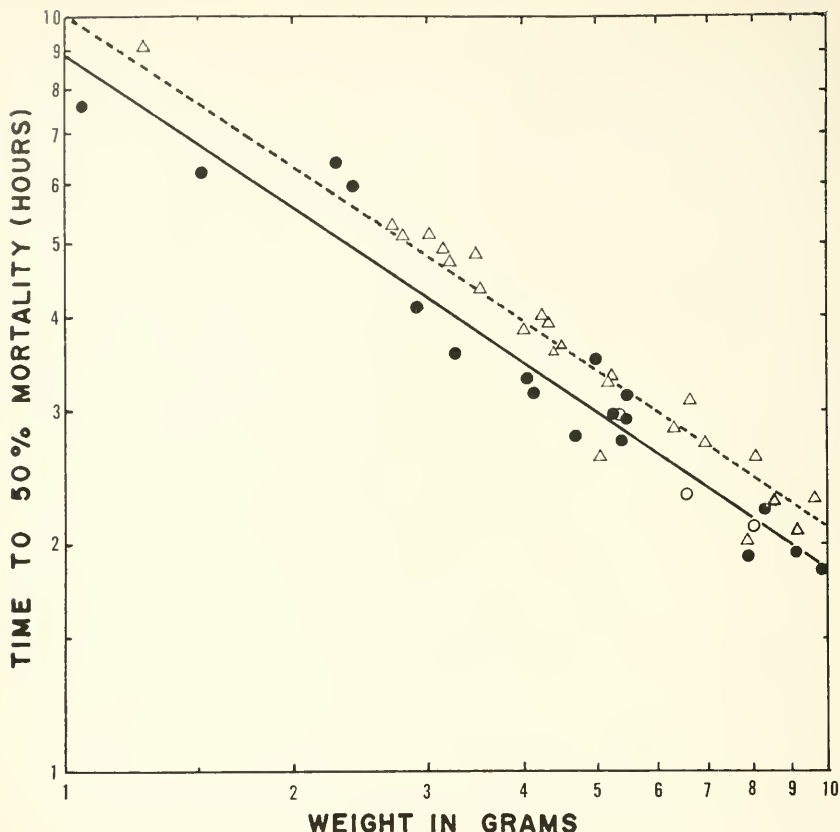


FIGURE 1. The regression of mean weight of anesthetized and non-anesthetized groups of *Girella nigricans* on the time to 50-percent mortality.

The abscissa is the mean weight in grams of 10 *Girella* of similar size; the ordinate is the time of 50-percent mortality in hours corrected for available oxygen. Experiments were performed in sealed 1 gallon jars. The black faced circles represent control groups; the open faced triangles represent anesthetized groups. Four anesthetics, tertiary amyl alcohol (1.5 ml./gal.), methylparafynol (1.0 ml./gal.), chlorobutanol (1 gr./gal.) and M.S. 222 (1 gr./gal.), were used. No significant difference exists in the anesthetized groups; the data have been pooled. The regression equations for the anesthetized and control groups are, (1) anesthetized, $Y = (9.94)X^{-0.672}$, (2) controls, $Y = (8.82)X^{-0.671}$. No stimulation was used in the experiments. The difference between the means and regressions for the anesthetized and control groups is significant at the one percent level of probability. The three open faced circles are non-anesthetized groups treated with a buffer to maintain a constant pH; no difference from controls exists.

stimulated during the experiments, with the exception of the controls indicated by open faced squares in Figures 2 and 3. Covariance analysis of the data for the lower temperatures revealed that a significant difference existed between the means and regressions of all groups ($p < 1$ percent), but not between the slopes ($p > 5$ percent). Analysis of the data for stimulated groups at the higher temperature indicated a significant difference ($p < 1$ percent) existed between the means and regressions of the control and two anesthetized groups, but not between

the individual anesthetized groups. In contrast, groups of *Fundulus* pretreated in M.S. 222 at the high temperatures were not found to differ statistically from the stimulated groups (data for M.S. 222 not plotted for this reason). The M.S. 222 treated groups showed a slight loss of reactivity during the first 30 to 60 minutes of the experiments,

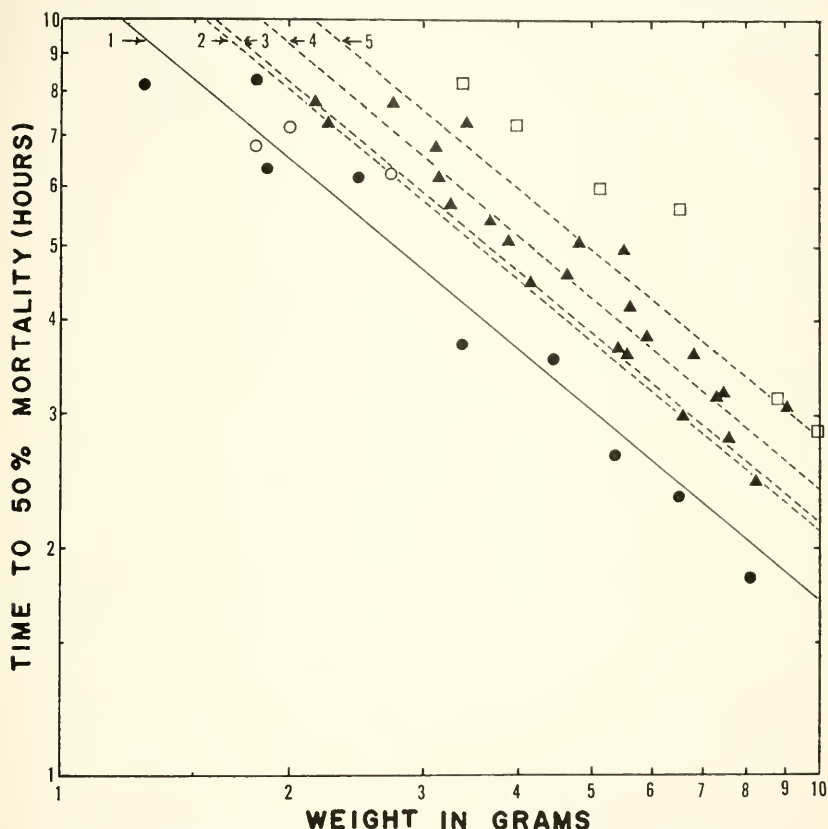


FIGURE 2. The regression of mean weight of anesthetized and non-anesthetized groups of *Fundulus parvipinnis* adapted to salt water and acclimated to 18-21° C. on the time to 50-percent mortality.

Experiments were performed in sealed 1-gallon jars. The abscissa and ordinate are the same as for Figure 1. Black faced circles represent stimulated control groups; black faced triangles represent stimulated anesthetized groups; open faced circles represent groups treated with 4 grains of sodium amytal/gal. of sea water. Open faced squares represent non-stimulated control groups acclimated at 14-15° C. Black triangles are pooled results from the 4 anesthetics cited below. The regression lines drawn through the data were computed from a common slope of -0.838 . The lines and equations are: (1) $Y = (11.64)X^{-0.838}$, stimulated controls, (2) $Y = (14.45)X^{-0.838}$, stimulated and pretreated with one ml. methylparafynol/gal., (3) $Y = (14.79)X^{-0.838}$, stimulated and pretreated with one grain M.S. 222/gal., (4) $Y = (16.74)X^{-0.838}$, stimulated and pretreated with 2 ml. tertiary amyl alcohol/gal. (5) $Y = (19.13)X^{-0.838}$, stimulated and pretreated with one grain chlorobutanol/gal. The use of these anesthetics produced varying increases in the time to 50-percent mortality in comparison to controls. This is indicated by the displacement of the data for anesthetized groups and can be evaluated by comparison of the alpha coefficients of the above equations. Sodium amytal had no effect.

but after this period they appeared as reactive as the stimulated controls, a result in distinct contrast to all the other anesthetized and pretreated groups of *Fundulus* at both acclimation temperatures and including the M.S. 222 treated *Fundulus* at the lower temperatures. This anomaly will be taken up in a later section.

Comparison of the time to 50 percent mortality of the anesthetized and stimulated groups of *Fundulus* (black faced triangles) with the stimulated controls (black faced circles) in Figures 2 and 3 indicated the considerable prolongation in time to death effected by the induction

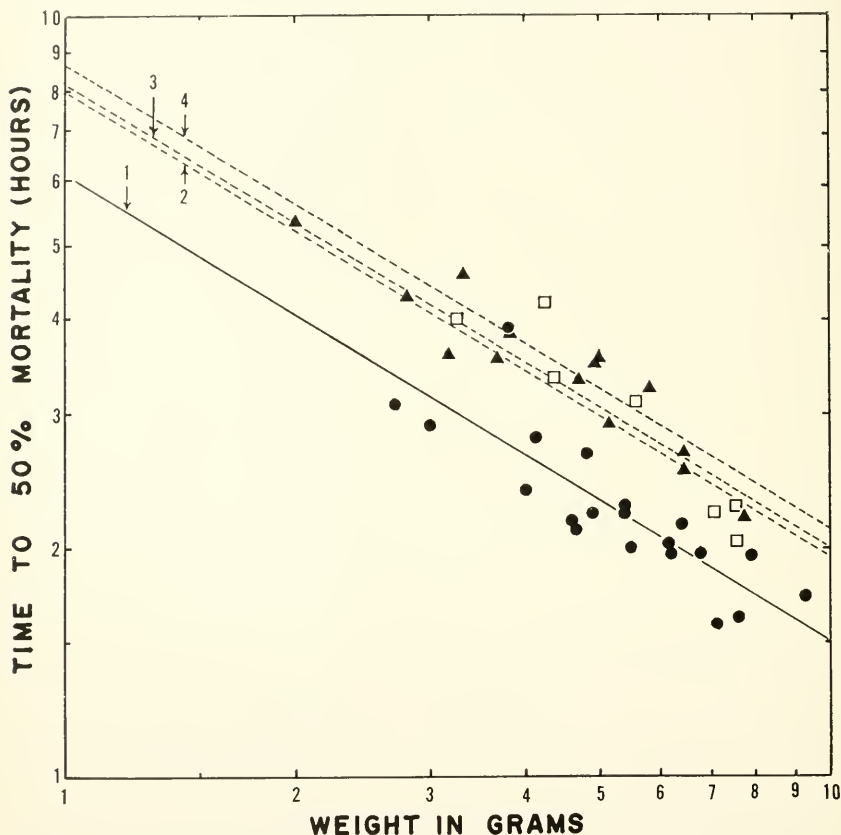


FIGURE 3. The regression of mean weight of anesthetized and non-anesthetized groups of *Fundulus parvipinnis* adapted to salt water and acclimated to 24°-27° C., on the time to 50-percent mortality.

Experiments were performed in sealed 1-gallon jars. The abscissa and ordinate are the same as for Figure 1. Black faced circles represent stimulated control groups; black faced triangles, stimulated anesthetized groups; open faced squares, non-stimulated controls. Results for two anesthetics, tertiary amyl alcohol and methylparafynol, are pooled (black faced triangles). Regression lines drawn through the data were computed from a common slope of -0.606 . The equations are (1) $Y = (6.112)X^{-0.606}$, stimulated controls (2) $Y = (7.904)X^{-0.606}$, stimulated, and pretreated with one ml. methylparafynol/gal. (3) $Y = (8.111)X^{-0.606}$, non-stimulated controls (4) $Y = (8.610)X^{-0.606}$, stimulated and pretreated with 2 ml. tertiary amyl alcohol/gal. The use of anesthetics produced almost a total inhibition of reactivity to stimulation as judged by the non-stimulated controls. Evaluation of his inhibiting effect can be obtained by comparison of the alpha coefficients of the regression lines.

of sedation (Stage I-2). In fact, with but one exception (the 3.8 gm. control group that died at 3.87 hours, Figure 3) the anesthetized groups did not overlap the control groups.

The results for the control groups that were not stimulated (open faced squares, Figures 2 and 3) are of considerable value to the interpretation of results. The values for the high temperature non-stimulated controls fall amongst the values for the stimulated anesthetized groups (Figure 3) and, in fact, when analysed by covariance were found not to differ significantly. Similar data for non-stimulated controls in the 18- to 21-degree C. groups are unfortunately not available, but values for several groups acclimated and tested at 15 degrees C. are indicated. If due allowance is made for the fact that metabolism decreases with temperature (even in thermally acclimated animals) the values would probably fall in the region of regression line five (chlorobutanol treated groups) of Figure 2. This invites the conclusion that the effects of the anesthetics were to decrease the oxygen consumption of the stimulated groups to the level of the non-stimulated groups. Such results are in full accord with the supposition proposed at the beginning of this section, that, induction of sedation should eradicate the effects of stimulation (i.e., eliminate reactivity) and thus increase the time to 50 percent mortality by causing a decrease in oxygen consumption.

Comparison of the alpha coefficients for the different anesthetized groups with the control groups (see legend, Figures 2 and 3), in the manner described for *Girella* would give different values of inhibition of mortality for the various anesthetics (chlorobutanol more effective than the other anesthetics, Figure 2). However, it is felt that the differences demonstrated are probably the result of slightly different degrees in the depth of sedation. For instance, McFarland (1959b) in a more detailed description than that given in Table 1 of the behavioral reactions of anesthetized *Fundulus* and *Girella*, has indicated that during the induction of deep sedation there is an initial loss of reactivity to visual stimuli, but at this time the fish will still react to vibrational stimuli. Later in the stage a total loss of reactivity to both visual and vibrational stimuli occurs. Certainly, the fact that tertiary amyl alcohol and methylparafynol were totally effective in inhibiting the effect of stimulation in the groups of *Fundulus* tested at the higher temperatures (Figure 3), but not as effective in groups tested at lower temperatures (Figure 2) is best explained by such a possibility.

Another result of importance, and one also related to the depth of anesthesia, concerns the length of pretreatment in anesthetic. For instance, six of the 20 control groups plotted in Figure 2 (black faced circles) were introduced into tertiary amyl alcohol without the normal one hour period of pretreatment. The data were lumped with controls in Figure 2 since no statistical difference existed. It appears, therefore, that an initial period of exposure to anesthetic is necessary before a significant loss in reaction (both behavioral and metabolic) to stimuli can occur. Many of the anesthetics tested were found to induce deep sedation in two to five minutes (visually). This suggests that visual indications of a loss of reactivity do not imply a corresponding immediate decline of the metabolism to basal levels. This contention is supported by the results of Black, Fry and Scott (1939), who reported

that the mere handling of fish when placing them in respiration chambers can cause a maximum oxygen uptake for several hours.

Observation of the difference in behavioral reactions of the anesthetized and control groups during periods of stimulation point to the beneficial effects of anesthesia in fish transport. The former hovered over the bottom or sat quietly upon it and showed no reaction to the flashing of lights in contrast to controls, which reacted by descending rapidly to the bottom and increasing the pectoral-fin movements. This would result in a higher metabolism in controls and, therefore, a more rapid reduction in the oxygen tension to lethal levels.

The limiting factor causing mortality in these experiments as already indicated was oxygen deficiency. The mean oxygen concentration at the time to 50 percent mortality was 0.25 ml./L (range 0.15-0.40) for groups of *Girella* and 0.22 ml./L (range 0.11-0.62) for groups of *Fundulus*. Values for pH declined from between 7.65 and 7.85 initially to a mean value of 7.10 (range 6.92-7.26) for groups of *Girella* and to 7.19 (range 6.95-7.48) for groups of *Fundulus*. Carbon dioxide increased from initial concentrations of three to six p.p.m. to a final mean value of 18.6 p.p.m. (range 14-30) for groups of *Girella* and to 12.4 p.p.m. (range 7-19) for groups of *Fundulus*. No significant differences occur between the final values for anesthetized and control groups.

The values for pH appear well above and for CO₂ well below reported lethal levels for fishes (McFarland and Norris, 1958). Nevertheless, the changes could affect the ability of *Fundulus* and *Girella* to utilize oxygen. To test this possibility three groups of non-anesthetized opaleyes were subjected to a buffer (tris-hydroxy methylaminomethane) to determine the possible interaction of pH, CO₂ and O₂ in changing the time to 50 percent mortality. The time of mortality of the three groups did not differ from the controls (Figure 1, open faced circles). In contrast to the controls, however, the pH and CO₂ concentrations changed only slightly at the time to 50 percent mortality (pH from 8.30 to 8.20; CO₂ from 0 to 2.0 p.p.m.), while the final O₂ concentration declined to 0.23 ml./L and agreed very well with the values for the non-buffered anesthetized and control groups. Apparently the decline in pH and the increase in CO₂ (from metabolism) did not cause a sufficient change in the utilization of oxygen to displace the time to 50 percent mortality.

In the closed-system mortality experiments with *Fundulus* buffers were not used to test the possibility of decreased pH and increased CO₂ affecting the time to 50 percent mortality. However, three groups were exposed to four grains of sodium amytal per gallon (Figure 2, open faced circles) an anesthetic that has considerable buffering action. The final pH and CO₂ values (pH of 7.60, 7.62, 7.82; CO₂ of four, three, four p.p.m.) are in the range of the initial values for all groups of *Fundulus*. The final O₂ concentrations were 0.17, 0.19 and 0.21 ml./L, again implicating oxygen as the primary lethal factor.

It is of interest that the time to 50 percent mortality of the sodium amytal treated groups (Figure 2) was not essentially different from the controls. Difficulties were encountered in attempting to induce and control anesthesia in fishes with this anesthetic. This difficulty is probably the result of a calcium antagonism of sodium amytal anesthesia (Onkst, *et al.*, 1957; McFarland, 1959a and b). For this reason sodium

amytal is not considered a good all-purpose anesthetic for fishes except where water is soft.

One further possibility was tested, i.e. that nitrogeuous wastes accumulating in the form of ammonia from metabolism might in part account for mortality. In all, 32 determinations for both inorganic and organic nitrogen of the water were performed with the following results:

Initial inorganic N (as p.p.m. NH_3) = trace (less than 0.005)

Initial organic N (as p.p.m. NH_3) = mean 0.15 (0.10-0.32)

Final inorganic N (as p.p.m. NH_3) = means 0.03 (0.00-0.09)

Final organic N (as p.p.m. NH_3) = mean 0.46 (0.075-1.30)

Inorganic nitrogen detectably increased during the course of the experiments, but the maximum value recorded (0.09) was far below lethal levels. The organic nitrogen increased approximately fourfold, presumably from metabolism. Ammonia from this source, however, was negligible and non-toxic, since it is in bound form as urea, creatine, etc. (Broekway, 1950).

Since oxygen appears to be the only demonstrable major factor implicated in mortality, the supposition that anesthetics cause increases in the time to mortality by causing decreases in metabolism was supported by the results.

The results indicate that anesthesia when properly induced can completely inhibit reaction to stimuli. Further, within the limits of size used in the experiments, this inhibition appears independent of size (see Figures 1, 2 and 3). In *Fundulus* the benefit of using anesthetics was not affected by higher temperatures. Certain anesthetics, like M.S. 222, however, appear to be more labile at higher temperatures. In addition, periods of anesthetic pretreatment are necessary for complete inhibition of reactivity, even though an apparent loss of visible reaction can be induced rapidly. The implications of these results and of anesthesia to the practical problem of fish transport will be examined in the following section.

Anesthesia and the Control of Excess Activity During Fish Transport

Most fish and game departments have fulfilled the need to transport more fishes by increasing the size and number of transport units and by improving mechanical features such as circulating pumps and aerating devices. Often, however, the basic physiologic requirements of fishes have not been fully appreciated in the design and operation of transport equipment. Several recent papers attempt to integrate practice and theory by relating important aspects of fish physiology to the design and to the operation of equipment (McFarland and Norris, 1958; McFarland, 1959a; Fry and Norris, 1959; and Norris, *et al.*, 1960).

In any transport operation the factors which limit the maximum weight of fishes that can be hauled are the causes of mortality. Ultimate causes of death in fishes are difficult to ascertain with certainty (Black, 1958; McFarland and Norris, 1958), but the factors most often implicated can lead to a depletion in the supply of oxygen to the tissues, a result not necessarily overcome by supplying high oxygen tensions in the water (McFarland, 1959a). The most important of these

factors are: dissolved oxygen (Haskell, 1940b), carbon dioxide and acidity (Vaas, 1952; McFarland and Norris, 1958), waste products (Brockway, 1950), temperature, and excess activity of fishes (Black, 1958). Since proper induction of deep sedation in fishes has been shown to reduce activity metabolism, it is apparent that anesthetics can be used during fish transport to directly control and reduce excess activity. Decreased activity of fishes will cause a reduction in oxygen depletion and a reduction in the accumulation of carbon dioxide, acidity and waste products from metabolism. Anesthetics, therefore, have the potential of directly controlling one and, in part, of indirectly controlling four of the six factors implicated in mortality of fish during transport.

Range of metabolic activity, the level of no excess activity and maximum load capacity for fish transport

The relationship between basal and activity metabolism of fishes and the effect of several variables on them has been recently reviewed by Fry (1957). Certain of these relationships are of prime importance to the transportation of fishes since they allow one to estimate the maximum allowable load that can be hauled when using anesthetics. Of immediate importance is the demonstration (see Fry, 1957) that in fishes the active rate of oxygen uptake (activity metabolism) is of the order of four to five times the basal metabolic rate when fishes are performing maximum sustained work. One can assume, therefore, that the total oxygen required by fishes during transport will not exceed four to five times their minimal requirements. Knowledge of the basal metabolic rates of a species and of the aerating efficiency of a given transport unit should allow calculation of the maximum weight of fishes transportable (assuming constant acclimation and transport temperature).

Decreases in the oxygen tension of the medium have been shown to restrict the ability of many species of fishes, particularly trout, to be active (Fry, 1957). It seems plausible that during transport depletion of the oxygen supply of the medium by the fishes will automatically restrict their ability to be active. However, if the active metabolism was completely suppressed by sufficient declines in oxygen tension of the medium (activity requirements equal basal requirements) further reductions would result in distress and ultimately mortality since the fishes would not be able to meet their minimal requirements. During transport such a condition would be chaotic since the fishes would pack at the bottom of the tank. Indeed, apparently, more effort has gone into providing excess aeration on transport units than into the control of any other variable (Norris, *et al.*, 1960).

The condition where the active respiration equals the basal metabolism has been defined as the "level of no excess activity" by Fry (1947). Recently, Basu (1959) has reported that increased carbon dioxide, like decreased oxygen, can produce a "level of no excess activity." In actual transport it is probable that "no excess activity" would result or at least be approached from both depleted oxygen and increased carbon dioxide, which often go hand in hand during transport, and also from the accumulation of waste products and large decreases in temperature.

A metabolic condition slightly above the "level of no excess activity" would be desirable in transporting fishes since the oxygen requirements would approach basal levels. However, where this condition is induced by a variable, like oxygen, which in itself is lethal on further change, or becomes lethal by slight changes in other variables such as carbon dioxide, ammonia and temperature, the "level of no excess activity" as a means of metabolic control becomes extremely hazardous. For this reason the utilization of agents like carbon dioxide, as suggested by Fish (1943), which are limiting factors in themselves, as aids in transporting fishes, are highly undesirable.

The concept of "no excess activity" clearly indicates the value of anesthesia in transporting fishes. If the proper depth of anesthesia (deep sedation) was induced during transport a condition approaching the "level of no excess activity" would exist since the fishes would be metabolizing near basal rates. Under these circumstances "no excess activity" would be realized in the presence of oxygen and carbon dioxide tensions and ammonia concentrations that are well above limiting levels. Anesthesia is therefore extremely valuable for producing a condition of "no excess activity" during transport because it removes the hazard of limiting factors.

Theoretical limits for the weight of fish that can be carried during transport by using anesthetics can be determined, if based on findings concerning activity metabolism in fishes. If it is assumed that during transport the activity metabolism approaches the maximum (four to five times the basal metabolism) and in a given transport system the load of fishes carried is balanced against the aerating system (oxygen requirements equal oxygen supply) it theoretically should be possible by using anesthetics to increase the weight of fishes carried by a factor of four to five. In practice this limit will not be realized, since the mere increase in the weight of fish carried decreases both the relative volume of water per fish and the total water volume in the system. Under these conditions the same accumulation rate of carbon dioxide and ammonia will produce higher concentrations in the water, all of which have an adverse effect on fish (see McFarland and Norris, 1958). The reduction in water volume from increased weights of fishes will result in a more rapid turnover rate (see Norris, *et al.*, 1960) since the pumping systems usually have a constant output. This should compensate to some extent for the higher concentrations of carbon dioxide and wastes, and the reduction in oxygen, but there is no reason to assume that aeration efficiency should be proportionally increased. Therefore, the actual upper theoretical limit of a fourfold increase in the weight of fish that can be transported by utilizing anesthetics to approach a "level of no excess activity" can probably not be realized in practice. More realistic estimates would place the limit at two- to three-fold increases. The doubling and occasionally the tripling of the normal weights of trout transported when using sodium amytal (Reese, 1953) are more in accord with the later estimate.

Control of hyperactivity and the prevention of bodily damage

Excess or hyperactivity of fishes can lead to mortality even when maximal loads are not transported. The researches of Black (1955, 1957a, b and c, and 1958) indicate that fishes when forced to exercise to

the point of fatigue often do not recover. During hyperactivity fishes accumulate high levels of lactic acid and incur oxygen debts that, if at all, are not paid for several hours. The fact that fishes are hyperactive during the initial phases of transport (Haskell, 1940b) and also that post planting mortality is common, even when loads are not maximal, indicates the desirability of inhibiting activity of fishes during transport. The induction and control of sedation should greatly reduce the possibility of fatigue occurring in fishes during transport. In fact, it is probable that the greatest advantage of using anesthetics during transport is prevention of the dire physiological side effects that result from hyperactivity (see Black, 1958) and not the increased load carrying capacity.

Sedation also reduces the possibility of self inflicted physical damage that occurs when highly disturbed fishes swim into the sides and bottom of transport tanks. If incorporated with the use of rounded tanks and the induction of mild orienting currents (see Norris, *et al.*, 1960) light to deep sedation should allow the handling and transport of exceedingly active fishes like tunas. As indicated earlier, this procedure has been at least partly successful in attempts to transport albacore.

Useful Anesthetics, Effective Concentrations and the Value of Pretreatment in Fish Transport

Of the anesthetics tested, ethyl alcohol, tertiary butyl alcohol (low potency) and M.S. 222 (labile) are considered the least desirable for transporting fishes. Sodium amytal is also considered undesirable since it is antagonized by calcium and therefore is difficult to use in hard or marine waters (Onkst, *et al.*, 1957; McFarland, 1959a, 1959b). The success of sodium amytal as a transport agent (Reese, 1953) can probably be attributed to the low calcium content of the waters generally used. Chlorobutanol and tribromoethanol are extremely potent and induce deep and prolonged sedation. However, because of the high potency each must be measured with precision and also, each must be pre-dissolved in organic solvents. For this reason they are not recommended for general use. Urethane, although effective, is also undesirable since it is relatively low in potency and is potentially carcinogenic (Wood, 1956).

Chloral hydrate, tertiary amyl alcohol and methyparafynol (= Dormison) all have properties that I regard as highly desirable. All have intermediate potency, are readily soluble in both fresh and salt water and induce deep sedation usually within 10 minutes and are compatible with calcium. Intermediate potency is a particular asset when using small volumes of transport water in that the possibility of overdosage from slight measuring errors is reduced. Also, deep sedation has been maintained for 24 hours with each of these anesthetics (and for 48 hours with tertiary amyl alcohol). Chloral hydrate is a solid and must be weighed prior to use. Both tertiary amyl alcohol and methyparafynol are liquids and can be readily measured with a graduate cylinder. In addition, all three are inexpensive and easily obtained.

Dosages that were found to be effective in maintaining sedation for at least 12 hours in killifish and opaleye are given in Table 4. Sedation was induced in mosquitto fish, *Gambusia affinis*, kelp bass, *Paralabrax clathratus* and albacore with but slight modification of these concen-

trations. Similar concentrations of these anesthetics should approximate this level of anesthesia in most species of fishes. In these experiments, increases in the dosage necessary to control deep sedation by from 1.5- to 3.0-fold caused the induction of partial loss of equilibrium, a stage of anesthesia already indicated as detrimental for transporting fishes. It is apparent, therefore, that if care is not exercised with the dosage of anesthetic while transporting fishes, mortality will occur. The report that doubling the dosage of M.S. 222 from 0.1 to 0.2 grams/gal., when carrying excessive loads of bluegill, often caused upsets in equilibrium (Stage II-I) and higher mortalities (Webb, 1958) indicates the practical importance of careful control of dosage of anesthetic.

TABLE 4

Approximate Concentrations of Anesthetics Useful for Transporting Fishes

(Concentrations given were effective in maintaining deep sedation in *Fundulus parvipinnis* and *Girella nigricans* for 12 hours or more.)

Anesthetic	Concentration in gms. or ml. / gal.	Remarks
Tertiary amyl alcohol	2 mls.	Oily liquid, intermediate potency
Methylparafynol (= Dornison)	1.0-2 mls.	Oily liquid, intermediate potency
Chloral hydrate	3.0-3.5 gms.	Solid, intermediate potency, induction of sedation slower than either above

Pretreatment of fishes in anesthetic prior to transport is necessary if anesthetics are to be used most effectively. Results from the closed-system mortality experiments indicate that without pretreatment anesthetized groups of fish die as soon as controls, even though the anesthetized fish are less reactive to external stimulation. Anesthetic pretreatment, therefore, seems essential where it is desired to transport maximum loads of fishes, a situation that demands control of both total oxygen uptake and excess movements of fishes. Anesthetic pretreatment will, of course, benefit any transport operation and it is recommended that whenever possible it be incorporated into operational procedure.

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SUMMARY

(1) Immobility of fishes is a condition beneficial to normal fisheries procedures like tagging, marking, weighing and stripping of fishes. Loss of reactivity to external stimuli is a condition beneficial to transporting fishes. Each of these conditions are discrete physiologic phases of the process of anesthesia in fishes and both can be induced and controlled for periods of time up to 24 hours with most soluble anesthetics.

(2) M.S. 222, tertiary amyl alcohol and methylparafynol are suggested as beneficial for the induction of deep anesthesia (immobility) since they act quickly and recovery is rapid.

(3) Recovery from anesthesia is complete, provided that respiratory movements have not ceased for more than a few minutes. No long-term effects of anesthesia were noted in opaleye and the wooly sculpin, nor did repeated inductions of deep anesthesia have any effect on opaleye.

(4) It is suggested that deep sedation is beneficial in fish transport since it reduces reactivity to disturbances met in transport and the possibility of physical damage and fatigue of fishes. Also, it results in decreased oxygen consumption and accumulation of wastes from metabolism. Experimental results indicate that anesthetized fish in sealed containers, when in deep sedation, live longer than controls. This difference is more pronounced when groups of fish are disturbed by external stimuli. The prolonged time to mortality in anesthetized groups is the result of a reduced rate of oxygen consumption resulting from the reduced activity of the fishes.

(5) Of several anesthetics tested, tertiary amyl alcohol at approximately 2.0 ml./gallon of water, methylparafynol at 1.5-2.0 ml./gallon and chloral hydrate at 3.0-3.5 grams/gallon are considered the most desirable anesthetics for transporting both marine and fresh water fishes. For maximum success, fishes should be pretreated for at least 10 to 15 minutes and preferably for one hour in anesthetic.

(6) If all fishes are metabolizing at maximum rates, the loads of fishes that can be transported (provided that the temperature is not reduced) theoretically cannot exceed four to five times the normal loads of a given transport unit. Because of mechanical factors and the fact that fishes do not necessarily metabolize at maximum rates during transport the use of anesthetics will probably allow no more than a doubling or an occasional tripling of normal loads.

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NOTES ON THE LIFE HISTORY OF THE BARRED SURF- PERCH, *AMPHISTICHUS ARGENTEUS* AGASSIZ, AND A TECHNIQUE FOR CULTURING EMBIOTOCID EMBRYOS¹

EDWARD L. TRIPLETT
Department of Biological Sciences
University of California, Santa Barbara
Goleta, California

INTRODUCTION

The life histories of embiotocid fishes in general are fragmentary. Several workers have investigated aspects of their embryology (Eigenmann, 1889, 1890, 1894, Girard 1854, Ryder 1885, Turner 1938), but only a few species have been studied in detail. Hubbs (1921) studied *Micrometrus minimus* (Gibbons) and *Micrometrus aurora* (Jordan and Gilbert), and later Hubbs and Hubbs (1954) published valuable information concerning *Brachyistius frenatus* Gill. Tarp (1952) gives a complete bibliography of work done on the Embiotocidae.

While this study of *Amphistichus argenteus* was in progress, it was learned that a similar project was being carried out by the California Department of Fish and Game under the supervision of Mr. John G. Carlisle, Jr. (in press). On two occasions notes were compared and found to be corroborative in almost all respects.

MATERIALS AND METHODS

The fishes used in this investigation were collected at Goleta Point on the Santa Barbara Campus of the University of California. Angling gear and a beach seine were both employed, but all statistics are based on fish obtained with the beach seine. These came from three hauls, yielding 652 fishes, made at two-week intervals in November and December of 1956.

Age determinations were made by counting scale annuli. Those fish without winter annuli are here referred to as being in the zero-year group; those with one winter annulus are called one-year-olds, and so forth. (*A. argenteus* scales exhibit a natal annulus similar to that described by Hubbs (1921, 1954) for other embiotocids. These natal annuli were not used in age determinations.)

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HABITS AND HABITAT

Amphistichus argenteus is usually found in relatively shallow water a short distance from shore. However, individuals have been observed by the author on rare occasions in the kelp beds off Goleta Point, California, at a depth of about 25 feet; and Conrad Limbaugh (personal communication) has collected others at depths as great as 78 feet off Oceano, California. The species commonly occurs above sandy bottoms.

The stomach contents of 30 fishes were found to be composed of a variety of animals, by far the most common of which was the sand crab, *Emerita analoga*. Two species of limpets (*Acmaca* spp.), goose-neck barnacles (*Mitella polymcrus*), and much unidentifiable debris were also seen.

EMBRYOLOGY

The early development of *A. argenteus*, as in all embiotocids, takes place within a cavity in the single bilobed ovary. The ovarian cavity in this species is divided by 10 longitudinal folds which are free ventrally and attached at the dorsal mid-line. They are thin and highly pleated, thus presenting a large surface area in a small space. One or both of the peripheral folds are occasionally smaller and are sometimes attached to adjacent folds rather than the dorsal ovarian wall.

Oocytes in various stages of maturation may be found in the tissues of the ovarian folds at different times during the year. Mature follicular ova are most commonly found during the early winter months. Turner (1938) reported that in *Cymatogaster aggregata* fertilization takes place within the follicle. The site of fertilization in *A. argenteus* remains unknown. Of all the specimens examined none contained fertilized follicular eggs; nor did any contain fertilized uncleaved eggs in the ovarian cavity. However, two females did contain in their ovarian cavities not only larval embryos but unfertilized eggs as well. The first, a two-year-old contained 18 embryos, averaging 9.0 millimeters in standard length, and a single unfertilized egg. The second, also a two-year-old, contained 12 embryos averaging 4.5 millimeters in standard length and 13 unfertilized eggs. This observation cannot be taken to indicate that fertilization necessarily takes place in the cavity since it could be argued that these eggs might normally have been fertilized in the follicles, but that in the absence of spermatozoa they were liberated unfertilized into the ovarian cavity. Furthermore, this observation should not be taken as an indication of superfetation since there was no assurance that the unfertilized eggs would have developed further.

Eigenmann (1889) has reported that in *Cymatogaster aggregata* cleavage of the very small, sparsely-yolked eggs approaches the holoblastic-type. In contrast, the eggs of *Amphistichus argenteus*, though also small (0.4 mm.), undergo a more typically fishlike meroblastic-type of cleavage with the resultant formation of a discoidal germinal disc at the blastula stage. What little yolk is present has been used up after approximately the first week of development, at which time the embryo becomes completely dependent upon the parent for nutriment.

When the embryos reach a length of about four millimeters, the yolk has been completely resorbed; and the digestive tract takes on a configuration peculiar to the Embiotocidae. The hindgut becomes hyper-

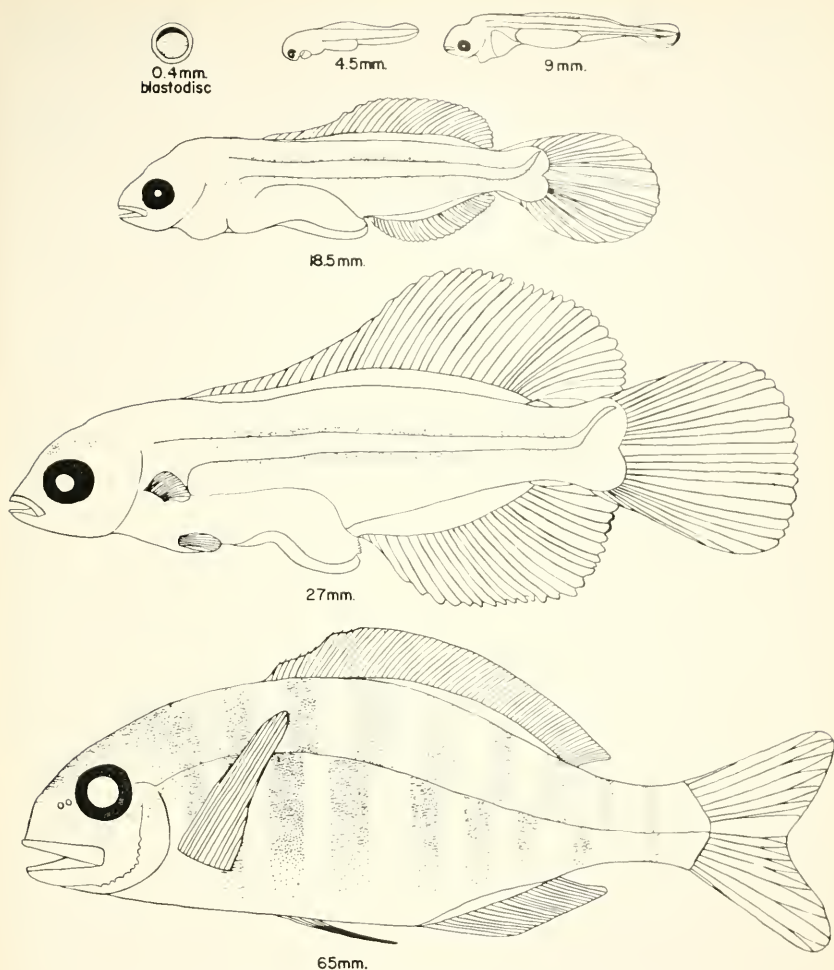


FIGURE 1. Projection drawings of *Amphistichus argenteus* embryos in various stages of development.

trophied, thin-walled and highly villified. It is presumably here that most of the absorption of foods takes place, materials being brought into the mouth by ciliary action and by the movement of the gills. Embryos larger than about four millimeters exhibit peristaltic movements of the hindgut. The food taken in consists essentially of ovarian fluid and epithelial cells sloughed from the wall of the ovary.

As development progresses, the dorsal, caudal, and anal fins grow at a much greater rate than the linear growth of the body (Figure 1). It has been found, in fact, that the total area of the fins increases in almost direct proportion to the total mass (Figure 2). This would indicate that these hypertrophied fins are important in the exchange of gaseous materials. The role of the fins as organs of gaseous exchange is further supported by the fact that they are very heavily vascularized and contain capillary tufts in distal dermal flaps. Eigenmann (1894)

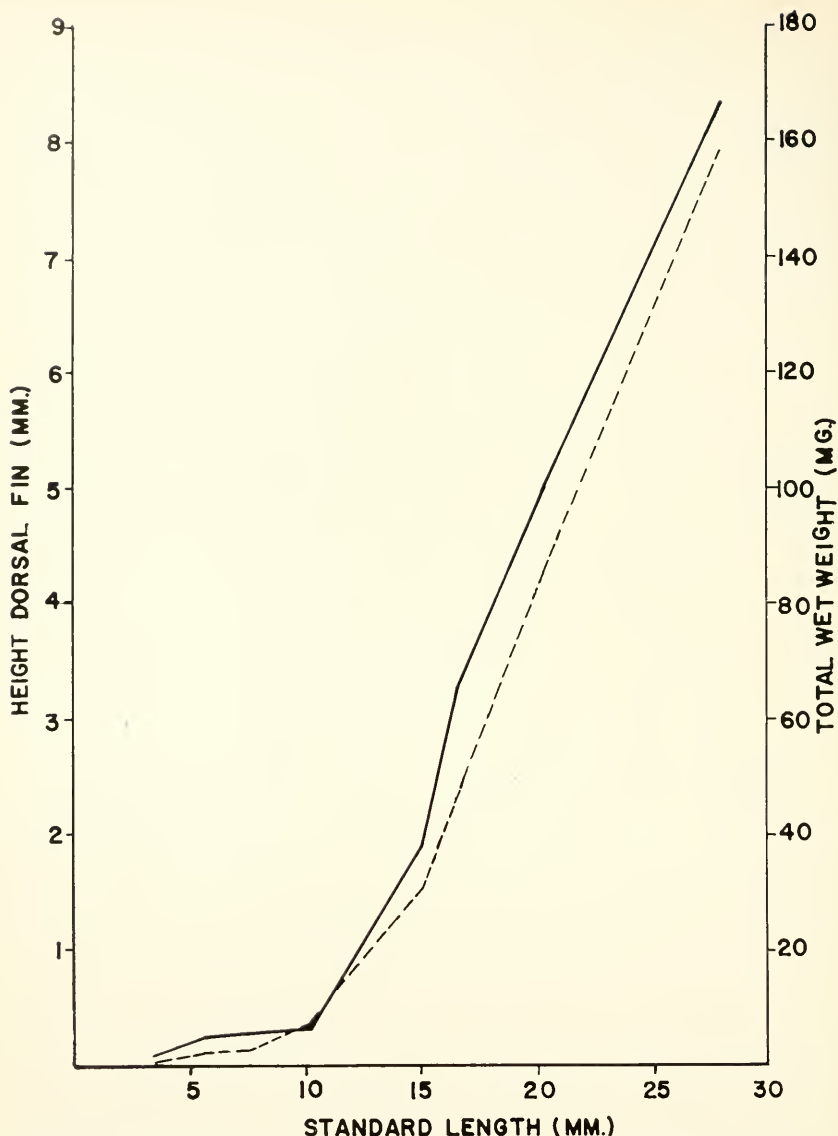


FIGURE 2. The length of the longest ray of the dorsal fin and the total wet weight of *A. argenteus* embryos each plotted as a function of standard length.

noted a similar situation in *Cymatogaster aggregata*. Shortly before birth these fins begin to be resorbed so that adult fin-body length proportions are achieved soon after birth.

In order to study the exchange of materials between parent and embryo more closely, it was decided to attempt the culture of embryos *in-vitro*. Both *Cymatogaster aggregata* and *A. argenteus* were used.

The embryos used ranged in standard length from 20 to 40 millimeters. Intra-ovarian embryos (of about 40 millimeters) which were

due to be born within approximately one week and which had almost completely resorbed their hypertrophied fins were capable of living in sea water. These embryos behaved quite like newborn fishes, swimming constantly in an upright position and feeding on pieces of mussel (*Mytilus californianus*) placed in the container. The 16 embryos tested were alive after 26 days and were fixed at that time. Embryos slightly younger but of essentially the same length and which had not begun to resorb their fins behaved quite differently. Twenty such embryos placed in a saltwater aquarium lived for periods ranging from two to five days. These animals spent most of their time lying on their sides on the bottom of the container, occasionally fluttering several inches with snakelike undulations of the body. They were incapable of maintaining an upright position and apparently could not yet feed. Still younger embryos invariably died within two hours when placed in sea water. Sea water is hypertonic for these fishes, and it is possible that the young embryos had not yet elaborated the osmoregulatory mechanism that must be operative in newborn fishes and adults.

Embryos that had not resorbed their fins and that ordinarily would have died in sea water, as just noted, could be kept alive in ovarian fluid. Two series of five fish each, one set 30 millimeters and the other 24 millimeters long, were maintained *in-vitro* in sterile ovarian fluids for periods as long as 10 days. It was necessary to change the medium daily and to maintain the temperature at 16 ± 2 degrees C. These animals could undoubtedly have been kept alive longer had ovarian fluid been more readily available.

The younger embryos have been kept alive as long as 30 hours in Ringer solution and with the addition of one percent glucose, they have been kept alive as long as five days.

The most satisfactory medium for culturing perch embryos was a modification of White's medium (1954). Its constituents are as follows:

A		B	
NaCl	140.00 g.	Fe(NO ₃) ₂ ·9H ₂ O	0.025 g.
KCl	7.50 g.	H ₂ O	1000 ml.
MgSO ₄ ·7H ₂ O	11.25 g.		
CaNO ₃ ·4H ₂ O	4.20 g.		
H ₂ O	1000 ml.		
C		D	
Dextrose	118.00 g.	proteose-peptone	2.00 g.
H ₂ O	1000 ml.	tryptone	2.00 g.
		yeast extract	2.00 g.
		H ₂ O	1000 ml.
E		F	
Na ₂ HPO ₄ ·12H ₂ O	23.85 g.	KH ₂ PO ₄	.908 g.
H ₂ O	1000 ml.	H ₂ O	1000 ml.

The six components are autoclaved separately. Fifty ml. each of parts A, B, C and D and 20 ml. each of parts E and F are added to 760 ml. of sterile water.

Embryos kept in finger bowls in this solution have been maintained alive and healthy over a period of 30 days, and they could have been maintained longer. During this period the embryos grew in length and differentiated normally.

It was noted that *in-vitro* embryos "metamorphose" more rapidly than animals contained within the parental ovary. Very soon after

transfer to the culture medium the dermal flaps on the fins and the hypertrophied hindgut begin to atrophy. Guanine and melanin deposition is rapid so that very soon the originally transparent embryo acquires a pigment pattern approaching that of the newborn fish. Possibly the lack of a hormone(s) secreted by the parental ovary is responsible for this phenomenon.

AGE AT FIRST MATURITY

Males were judged to be sexually mature if motile spermatozoa could be observed in preparations made from minced testes. Of 15 fishes in the zero-year group, all except one contained some mature spermatozoa. Testis preparations made from all age groups with one or more winter annuli exhibited many mature spermatozoa. In contrast to the situation in *Micrometrus minimus* and *Micrometrus aurora* (Hubbs 1921), the unborn young examined were without exception immature. It was established, then, that sexual maturity is reached in the male of *Amphistichus argenteus* sometime between birth and the first winter. This is also the case in several other embiotocids (Hubbs and Hubbs 1954).

Maturity in females is reached at a much later date. Of the 30 zero-year-old females examined between October and March, all contained small follicles in the ovarian folds, but none had eggs or embryos in the ovarian cavity. The same was true of 20 one-year-olds examined over the same time interval. In contrast, all two-year-olds examined after the middle of January contained developing embryos; those examined before that time contained none, though many ripe follicular eggs were found. Three three-year-olds were caught with hook and line in early December, and all had developing embryos; one three-year-old fish caught in early November contained no embryos. One four-year-old was caught on November 2, and at that time contained eggs in cleavage stages in the ovarian cavity.

These data indicate that female fish with fewer than two winter annuli do not bear young. They indicate further that the time of ovulation in mature fishes can be correlated with age; the older the fish the earlier in the season will be its time of ovulation.

GESTATION PERIOD AND SIZE OF BROOD

Newly born fishes begin to appear in the intertidal zone during the latter part of April, and fishes with term embryos in their ovarian cavities continue to be caught until the end of June. These data, coupled with those concerning time of ovulation, indicate the gestation period is about five months. The four-year-olds carry their young from about November to April, the three-year-olds from about December to May, and the two-year-olds from about January to June.

The young are born in relatively small numbers per female and the number per individual is almost directly proportional to the age (size) of the parent. Two-year-old fish bear about 20 young, three-year-olds about 40, and four-year-olds about 70 young.

SUMMARY

The following points on the embryology and life history of *Amphistichus argenteus* have been established:

1. The eggs, though relatively small, are distinctly telolecithal and in early development follow a pattern characteristic of most teleosts.
2. As the development proceeds the fins increase in area proportionally to the increase in total weight. These hyperdeveloped fins, along with pleated folds projecting from the ovarian wall, probably serve as pseudo-placenta.
3. Males attain sexual maturity sometime between birth and the first winter. Females with fewer than two annuli probably do not bear young. Old females bear more young per season and ovulate earlier than do young females.
4. The gestation period is about five months and, depending upon the age of the parent, occurs sometime between November and June.
5. Embryos of *A. argentus* and *Cymatogaster aggregata* can be made to grow and differentiate *in-vitro* using a modification of White's medium as a culture fluid.

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THE FAMILIES AND GENERA OF THE LAMPRIDIFORM (ALLOTRIOGNATH) SUBORDER TRACHIPTEROIDEI¹

VLADIMIR WALTERS

Department of Fishes and Aquatic Biology
American Museum of Natural History, New York

and

JOHN E. FITCH

Marine Resources Operations
California Department of Fish and Game

Owing to their scarcity, unusual shape, vivid coloration and frequently large size these fishes prompt discussion when captured or when occasional stranded individuals are found. In folklore some are associated with the abundance or scarcity of other species; thus the common names King-of-the-herring for *Regalecus glesne* among northern Europeans, and King-of-the-salmon for *Trachipterus trachipterus altivclis* (= *T. rex-salmonorum*) among Pacific Northwest Indians. *Regalecus glesne*, due to the fancied resemblance of its head and dorsal fin to a horse with fiery mane, when coupled with its immense size (estimated to 37 feet or more) and serpentine shape, may well be the basis for some of the reported sightings of sea serpents.

Three families, crestfishes, ribbonfishes and oarfishes, comprise the lampridiform suborder Trachipteroidei: Lophotidae, Trachipteridae, Regalecidae.² In recent years a comparatively large number of individuals belonging to this suborder, ranging in size from eggs to adults, has been taken on the shores and in the waters off the Americas. This material, together with specimens already in collections and the knowledge that has accumulated in the literature, offers opportunity to evaluate the systematics of the Trachipteroidei. Diagnoses for the suborder, families and genera are presented herein. In a subsequent paper the species will be enumerated, and the biology and evolution of the group will be discussed.

Representatives of all of the genera have been seen except for *Protolophotus* and *Agrostichthys*. The former is known from only two specimens found in Oligocene deposits of Iran (Arambourg, 1944; Walters, 1957). We are most grateful to G. M. Moreland, who examined two specimens of *Agrostichthys parkeri* in the Dominion Museum, Wellington, N. Z.; his observations form a large part of the generic diagnosis. All of the forms known from the Americas, including at least four un-

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² Members of all three families have been captured fairly frequently in California waters. At least five different species have been found in the stomachs of albacore and other deep-feeding tunas. However, before their role as potential competitors to, and food for, tunas (and other commercial species) can be determined, it is necessary to establish the characteristics of the group and to define the constituent parts (genera). This paper sets the stage for fishery workers to study these fishes not only in California but throughout the world.

described species, have been seen; all stages from egg to adult in *Zu* and *Trachipterus* are represented, all stages from larva to adult are represented for *Lophotus*, *Desmodema* and *Regalecus*, and *Eumecichthys* is represented only by subadults and adults. The number of specimens studied ranges from 5 of *Regalecus* to more than 100 of *Trachipterus*.

The material has been subjected to various methods of study: 1) external morphology and color pattern; 2) osteology through radiography, clearing and staining with alizarin, temporary clearing in glycerin, and dissection; 3) soft anatomy through dissection and histological work; 4) biometrics. Carl L. Hubbs generously turned over his notes and some radiographs on some of the anatomical features of California *Lophotus*. Norman B. Marshall kindly sent a radiograph of the type of *Eumecichthys fiski* which is in the British Museum (Natural History).

The anatomical studies on *Trachipterus arcticus* by Meek (1890), *Regalecus argenteus* by Parker (1886) and *Agrostichthys parkeri* by Dunbar (Benham and Dunbar, 1906) have been utilized, as well as a number of lesser papers which shall be cited when the species of trachipteroids are discussed. Through the perseverance of Italian students the egg development and morphology of the larvae have been made known for *Lophotus lacepedei* (Sanzo, 1940), *Zu cristatus* (Sanzo, 1918), *Trachipterus trachipterus* (LoBianco, 1908; Jacino, 1909) and *Regalecus glesne* (Sanzo, 1925); the information on *Trachipterus*, *Zu* and *Regalecus* was brought together by Spartà (1932).

Two studies on the metamorphosis of trachipterids were based on a mixture of species and thereby indicated a more profound series of morphological changes during ontogeny than actually occur; Emery's (1879 a, b) classical study on the metamorphosis of *Trachipterus t. trachipterus* (= *T. taenia*) employed larval flounders (*Arnoglossus* = *Ammopleurops*, see LoBianco, 1908) and Hubbs' (1926) study of *T. t. altivelis* (= *T. rex-salmonorum*) utilized a larval *Lophotus* sp. (specimen reexamined by Walters) for the small stages.

Many of the characters mentioned below refer to structures which are observable in few specimens because most trachipteroids become seriously damaged before they are finally preserved and put into a collection, and some of the characters apply to specific growth stages. A key designed to facilitate the identification of trachipteroids to genus is given at the end of the paper. Those differentiae were selected which should be determinable in all but the most badly damaged juveniles and adults, but the differentiae are not necessarily those we regard as the most significant for systematic purposes.

Order Lampridiformes (= Allotriognathi)

The group was established by Regan (1907) as a suborder of the Teleostei, and was later raised to ordinal status by him (1924). The outstanding feature is that the maxillae are protractile, they meet beneath the ascending processes of the premaxillae, and do not articulate with the palatines. For further details refer to Regan's papers. Regan (1907) stated the premaxillae of *Eumecichthys* are non-protractile but a radiograph of his specimen (the type of *Lophotes fiski*) shows them to be fully protracted.

Suborder Trachipteroidei (= Taeniosomi of Regan, and Trachipteroidei + Veliferoidei ex parte of Berg, 1940)

The frontals do not meet. A groove lies between the frontals, its floor containing the mesethmoid and orbitosphenoid ossifications; it receives the ascending processes of the maxillae and premaxillae when the jaw is retracted. The epioties meet. The suborbital series is absent except for the lachrymal and jugal. The pelvic bones do not articulate with the coracoids. The pectoral fin-rays are inserted on the scapula and three radials; one radial contacts the scapula and two contact the coracoid. Some rays may be branched in the pectoral, pelvic and anal fins but the rays are otherwise simple; no rays are articulated except for the portion of the pelvic ray buried in the blade of the "oar" in *Regalecus* and the tip of the first dorsal ray in large adult *Eumecichthys*. Each dorsal fin-ray bears a spine on either side, at its base. In juveniles and young adults each fin-ray bears a series of spinelets, imparting a sandpaper texture. The anal fin is reduced in size or absent. The swimbladder when present does not extend past the anus. The vertebrae number 62-200. There are 6 or 7 branchiostegal rays and 0 to 10 pelvic fin-rays. The embryo passes through a tubular-eyed stage but free-living individuals have normal eyes.

Three families: Lophotidae, Trachipteridae, Regalecidae

Family Lophotidae

Unicornfishes, Crestfishes

The vertebrae in the rear of the body are of the same length as those in the beginning of the body. Ribs are present. The haemal spines following the anal fin are expanded to resemble hockey sticks. Branched but not articulated rays are present in the pectoral and sometimes also in the pelvic and anal fins. The anal fin is reduced in size. The anus is near the posterior end of the body and lies within a cloaca. An ink sac is present; this discharges into the cloaca. A physoclistic swimbladder is present. The lateral line plates are smooth. The lateral line terminates at the base of the caudal fin, in the dorsal part of the tail. The dorsal fin originates anterior to the eye. The skin is smooth, without tubercles, and the dermis possesses closely-spaced black striations. The first dorsal ray and the lowest, next to the lowest, or third lowest caudal ray are robust and quill-like. The head and body are covered with small deciduous imbricate cycloid scales. A basisphenoid and posterior myodome are present. The egg capsule is spiny and the larva hatches with two pelvic fin-rays.

Three genera: † *Protolophotus*, *Lophotus* and *Eumecichthys*

† *Protolophotus* Walters (1957)

GENOTYPE: *Lophotes Elami* Arambourg (1944)

The pelvic fins are well-developed and inserted on the mid ventral line. The pelvic bones end posterior to the posteleithra, and the pelvic fins have 6 rays. Vertebrae 79.

*Lophotus Giorna (1809)*GENOTYPE: *Lophotus lacepede* Giorna (1809)

Maximum body depth is contained 5 to 8 times in standard length. The pelvic fins are small and inserted on the sides of the body, immediately below and behind the pectoral fins, and have 5 or 6 rays of which some may be branched. The pelvic bones lie parallel to the postcleithra. The anal fin base is longer than the pectoral fin base; there are 12 to 19 anal fin rays of which the posterior ones are branched. There are 220-263 dorsal fin-rays and 124-152 vertebrae. The swimbladder is well-developed and physoclistic; it consists of 3 chambers as follows: a thick-walled anterior chamber bearing the gas glands and receiving the retial supply anteriorly, above the esophagus; and two very long thin-walled posterior chambers which flank the ink sac. The ink sac begins beneath the latter half of the anterior chamber of the swimbladder. The color pattern is plain or spotted but never banded.

*Eumecichthys Regan (1907)*GENOTYPE: *Lophotes fiski* Günther (1890)

Maximum body depth is contained 18.8 to 30 or more times in standard length. The pelvic fins, when present, are minute and inserted on the sides of the body immediately below and behind the pectoral fins, and have 2 or 3 rays of which 1 may be branched. The pelvic bones when present lie parallel to the postcleithra. The anal fin base is shorter than the pectoral fin base; there are 5 to 9 anal rays, none branched. There are 310-392 dorsal fin-rays and 151-200 vertebrae. The swimbladder is reduced in size; it consists of a single thick-walled anterior chamber. The ink sac begins approximately one head-length (*sans rostrum*) behind the rear of the swimbladder. The color pattern consists of numerous (24 to 60) dark subvertical bands.

Family Trachipteridae

Dealfishes

The vertebrae in the rear of the body are 2.5 to 4 times longer than those in the beginning of the body, in adults. Ribs are absent. The haemal spines are all of the same form, not resembling hockey sticks. The anal fin is absent. The anus is in the forward half of the body or slightly behind mid-body, and there is no cloaca. There is no ink sac. The swimbladder is rudimentary or absent. The lateral line plates bear spines. The lateral line terminates at the base of the caudal fin in the ventral part of the tail, or extends onto the ventral lobe of the caudal fin. The dorsal fin originates above or slightly behind the eye. The skin is fairly uniformly covered with osseous tubercles in the adult, not arranged in bands. The pelvic fins are inserted on the midventral line and the pelvic bones end posterior to the postcleithra. The basisphenoid and posterior myodome are present. The posttemporals cover the parietals. The egg capsule is smooth and the larva hatches out with 3 pelvic fin-rays. The rays in the nuchal pennant, pelvic fins, and lower lobe of the caudal fin (when present) tend to fragment and disappear with age.

Three genera: *Zu*, *Trachipterus* and *Desmodema*.

Zu, new genus

GENOTYPE: *Trachipterus cristatus* Bonelli (1820)

Some of the rays in the nuchal pennant and pelvic fins bear serially-arranged structures which are black and bulbous in the larva but eventually each becomes a pale-colored membranous flap containing a bean-shaped black body at the junction with the fin ray; the same structures appear on the caudal filament but much later in life. The caudal fin contains well-developed rays in the upper lobe which are set at an angle to the caudal peduncle; the rays in the lower lobe often fragment as the fish grows but their bases persist as spines. The late larva and juvenile (some adults) have a caudal filament, consisting of 1 or 2 rays in the ventral lobe which become very long and thread-like. The body is covered with cycloid, imbricated, deciduous scales. The tubercles along the midventral line are flattened. The ventral profile is scalloped between the pelvic fin bases and the beginning of the tail. The lateral line is straight on the trunk, wavy on the tail, and extends onto the caudal filament between the rays where it is once more straight. A physoclistic swimbladder is present in the larva and small juvenile; in subadults and adults it is a small white fibrous rudiment. The gastric caecum is short, extending less than half the distance from the pyloric valve to the anus in adults. There are about 1.5 pairs of lateral line plates per postanal vertebra. The anus is in the midventral line, before the middle and behind the anterior third of the body. The larva on hatching lacks rays in the "second dorsal fin"; only the rays of the nuchal pennant are present, and the first lies above the rear edge of the opercle. The early larva has two longitudinal rows of 4 black spots each; in the upper row, the first lies beneath the base of the nuchal pennant, the second midway between the first and the third, the third above the anus, and the fourth is before the middle of the tail; in the lower row, the first is above and behind the pectoral base, the second is above the anus, the third is on the tail below and behind the fourth spot on the upper series, and the fourth is at the base of the caudal fin. The juvenile and adult color pattern consists of about 6 wavy dark vertical bars on the dorsal part of the trunk and 4 on the ventral part; the tail has about 6 complete vertical dark bands which are narrower than the interspaces. There are 62-69 vertebrae, 3 to 7 pelvic rays and the caudal fin has 8-12 rays in the upper lobe with 1-5 in the lower.

Zu was the storm god of Babylonian mythology and is a fitting name to be applied to a trachipteroid since, until recent years, these fishes were known mainly from individuals found cast ashore in the wakes of storms.

Trachipterus Goüan (1770)

GENOTYPE: *Cepola trachiptera* Gmelin (1789)

The dorsal and pelvic fin-rays do not develop serially-arranged bulbous or flap-like structures. The caudal fin has well-developed rays in its upper lobe which are set at an angle to the caudal peduncle; the rays in the lower lobe fragment as the fish grows but their bases usually persist as spines. The late larva and juvenile have a caudal filament in which the second and third rays from the bottom of the lower lobe

become very long and thread-like; the longer (third) ray may develop serially-arranged black bulbous structures. Scales are absent. The tubercles are enlarged and sharp-tipped along the midventral line. The ventral profile is entire between the pelvic fin bases and the beginning of the tail. There is no trace of a swimbladder. The gastric caecum is short, ending closer to the pyloric valve than to the anus in adults. There is very nearly 1 pair of lateral line plates per postanal vertebra. The lateral line is straight on the tail, and terminates at the base of the caudal fin. The anus is on the midventral line and lies close to the mid-length of the body in the adult. The larva hatches from the egg with rays developed in the anterior half of its dorsal fin, and the first dorsal ray is located above the eye. The newly-hatched larva has a dorsolateral and a ventrolateral streak of melanophores on its trunk. The juvenile has one or two horizontal rows of spots, each about equal to the eye in size, 1 to 5 spots per row; the spots in the ventral row tend to become longitudinal dark streaks; the dark markings tend to disappear in the adult. There are 69-101 vertebrae, 3 to 9 rays in each pelvic fin and the caudal fin has 6-10 rays in the upper lobe and 2-7 in the lower lobe.

Desmodema, new genus

GENOTYPE: *Trachypterus jacksoniensis polystictus* Ogilby (1897)

The dorsal, pelvic and caudal fin-rays do not develop bulbous or flap-like structures. The caudal fin rays are on the same axis as the caudal peduncle; a ventral lobe of the caudal fin is never present, and there is no caudal filament during ontogeny. The body is covered with non-imbricate, elliptical scales each with two slightly divergent spinose ridges (modified etenoid). The tubercles along the midventral line do not develop sharp tips. The ventral profile is entire between the pelvic fin bases and the beginning of the tail. The lateral line is straight on the tail, and terminates at the base of the caudal fin. There is no swimbladder. The gastric caecum is long, ending closer to the anus than to the pyloric valve in the adult. There are more than two pairs of lateral line plates per postanal vertebra. The anus is often situated on the left or right side instead of on the midline; in a 365 mm. juvenile it lies in the forward third of the body, and is presumed to lie even further forward in intact adults. The egg and early larva are unknown. Over a size range of 11 to 365 mm. the head and trunk are covered with a large number of dark polka-dots. In adults polka-dots are absent. There are 104-109 vertebrae, 7 to 10 rays in each pelvic fin and the caudal fin has 5 to 8 rays.

Desmodema means "band body"; the name would be more correctly spelled "*Desmodemas*" but for euphony the terminal letter is deleted.

Family Regalecidae
Oarfishes

The vertebrae in the rear of the body are 1.5 to 5 times longer than those in the beginning of the body. Haemal spines are absent. The anal fin is absent. The anus is in the forward third of the body and there is no cloaca. There is no ink sac. The swimbladder is absent. The lateral line plates are smooth. The pelvic fins are inserted on the midventral line. The basisphenoid and myodome are absent. The post-temporals attach to the skull behind the parietals. The egg capsule is smooth and the larva hatches out with 3 pelvic rays.

Two genera: *Regalecus* and *Agrostichthys*.

The oarfishes have been considered by some authors to belong to two distinct families, Regalecidae and Agrostichthyidae while others combine the oarfishes and ribbonfishes into the single family Trachipteridae. The familial difference between the Lophotidae and Trachipteridae is unquestionable, to consider only the unique ink sac of the Lophotidae. And yet, the larva of *Zu cristatus* is so strikingly similar to the larva of *Lophotus lacepedei* that as a first impulse one might be tempted to regard *Zu* and *Lophotus* as congeneric. On the other hand, the larva of *Regalecus* differs strongly from those of *Lophotus*, *Zu* and *Trachipterus*; this, coupled with the osteological features listed above in addition to unique structural features possessed by *Regalecus* serves to separate further the oarfishes from the ribbonfishes. The structure of *Agrostichthys* is too imperfectly known to permit a more exhaustive family diagnosis at this time, and possibly it is at least subfamilially distinct from *Regalecus*.

Regalecus Brünnich (1771)

GENOTYPE: *Ophidium glesne* Ascanius (1788)

The dorsal fin begins above or before the anterior quarter of the orbit. Some of the rays in the nuchal pennant and pelvic fins have serially-arranged structures which are black and bulbous in the larva but in the juvenile (180 mm.) each becomes a pale-colored flap containing a black bean-shaped body at the junction with the fin ray; the same structures appear on the caudal fin of older juveniles; in subadults (1760+ mm.) these are pale-colored and glandular in appearance; in the adult these are represented by club-like fleshy thickenings and the blade of the pelvic "oar". The caudal fin rays are on the same axis as the caudal peduncle; there is no separate, ventral lobe of the caudal fin and there is no caudal filament formed. Scales are absent. The skin along the sides of the body is underlain by cartilage or white fibrous connective tissue, which is thickened to form 4 to 6 longitudinal ridges or carinae; a horizontal septum of cartilage or white fibrous connective tissue extends mediad from each carina to divide the muscle mass dorsad of the coelom into 5 pairs of cartilage or connective-tissue enclosed longitudinal compartments. These longitudinal structures completely disrupt the myotome pattern. The rounded tubercles are enlarged on the carinae, and the tubercles are widely separated between the carinae; along the midventral line the tubercles are verrucose. The ventral profile is entire. The lateral line is straight, runs above the lower quarter of the trunk on the next to the lowest carina, and consists of a chain of oblong plates set loosely in the skin, each plate pierced by a tube. The gill rakers are numerous (40-58), long and spiny. The gastric caecum is extremely long, ending about halfway between the anus and the tip of the tail. The anus is on the midventral line, in the anterior third of the body. The newly-hatched larva has a few melanophores along the base of the dorsal fin fold and around the bases of the pectoral fins. The late larva (24 mm.) has two longitudinal stripes of melanophores. Juveniles (45.8 mm.) have incomplete diffuse vertical bands and spots on the trunk; or the trunk and tail are covered with polka-dots (375-1240 mm.). The adult has irregular

oblique dark streaks on the trunk and polka-dots on the tail. The premaxillae are perpendicular to the frontal profile, and the maxillae are horizontally ovate. There are no teeth in the mouth. A subcranial crest is present. The large parietals extend forward between the frontals. The preorbital length of the neurocranium equals half the orbital diameter. Ribs are present. The vertebrae bear neural spines and haemapophyses, but haemal arches do not form. There are 143-151 mymeres (in the larva), 1 to 5 pelvic fin rays and 3 or 4 caudal fin rays arranged as in *Desmodema*.

Agrostichthys Phillipps (1924)

GENOTYPE: *Regalecus parkeri* Benham (1904)

The dorsal fin begins above or behind the posterior quarter of the orbit. Some of the rays in the nuchal pennant have serially-arranged bulbous structures. Scales are absent. The sides of the body are without carinae; though the bony tubercles are in six ill-defined longitudinal bands on each side of the body they are not grouped into alternating strips of large and small tubercles. The tubercles are flattened along the midventral line. The ventral profile is entire. The lateral line is straight and runs close to the midventral line on the trunk. The lateral line plates are bound in epidermis to form a continuous tube; there are small pores above and below the tube. The anus is on the midventral line, in the anterior third of the body. There are few gill rakers (8-10), all smooth. The gastric caecum does not extend past the anus. The color pattern of the adult consists of numerous broad dark complete vertical bands at regular intervals on the trunk and tail. The premaxillae extend forward in an almost straight line from the frontal profile, and the maxillae are vertically ovate. Teeth are present on the vomer and dentaries. There is no subcranial crest. The small parietals lie entirely behind the frontals. The preorbital length of the neurocranium is about equal to the diameter of the orbit. The vertebrae throughout are represented only by scarcely ossified centra; there are no spines or other processes. There are an estimated 170 vertebrae, and 1 pelvic fin ray; the caudal fin is unknown.

ARTIFICIAL KEY TO THE FAMILIES AND GENERA OF THE TRACHIPTEROIDEI

- 1a. Anus near posterior end of body. Anal fin present. Skin smooth.
Ink sac present in recent forms. LOPHOTIDAE (2)
- 1b. Anus near middle of body, or further forward. Anal fin absent.
Skin roughened by numerous bony tubercles. Ink sac absent. (4)
- 2a. Pelvic fins inserted on midventral line. Vertebrae 79. Oligocene.
† *Protolophotus*
- 2b. Pelvic fins absent or inserted on sides of body, close to pectoral
fins. Vertebrae more than 120. Recent.
- 3a. Body depth 5 to 8 in standard length. Anal fin base longer than
pectoral fin base. Color pattern plain or spotted. Vertebrae 124-
152. *Lophotous*

- 3b. Body depth 18.8 to 30 in standard length. Anal fin base much shorter than pectoral fin base. Color pattern banded. Vertebrae 151-200. *Eumecichthys*
- 4a. Basisphenoid and posterior myodome present. Lateral line plates each with a spine. Bony tubercles not arranged in ill-or well-defined lengthwise bands along the sides of the body. Vertebrae 62-109. TRACHIPTERIDAE (5)
- 4b. Basisphenoid and posterior myodome absent. Lateral line plates smooth. Bony tubercles arranged in ill-defined lengthwise bands or pronounced lengthwise ridges, along the sides of the body. Vertebrae 143 to about 170. REGALECIDAE (7)
- 5a. Ventral profile scalloped between pelvic fin bases and beginning of tail. Lateral line wavy on tail. Tubercles flattened on midventral line. Color pattern of dark vertical bars or bands. Deciduous imbricated cycloid scales. Vertebrae 62-69. *Zu*, new genus.
- 5b. Ventral profile entire. Lateral line straight on tail. Color pattern uniform, polka-dotted, or with few large dark spots or longitudinal streaks. Tubercles flattened or sharp-tipped. Scales absent or etenoid. Vertebrae 69-109. (6)
- 6a. Color pattern uniform or with several equidistant eye-sized black spots and usually one or more longitudinal dark streaks. Tubercles along midventral line sharp-tipped. Scales absent. One pair of lateral line plates per postanal vertebrae. In adults, tip of gastric caecum lies nearer pyloric valve than anus. Caudal fin with 6 to 10 rays in the upper lobe, which is set at an angle to the caudal peduncle, and 2 to 7 rays or their rudiments in the lower lobe. Vertebrae 69-101. *Trachipterus*.
- 6b. Color pattern uniform or polka-dotted. Tubercles along midventral line are not sharp-tipped. Deciduous nonoverlapping modified etenoid scales. Two or more pairs of lateral line plates per postanal vertebrae. In adults, tip of gastric caecum lies closer to anus than to pyloric valve. Caudal fin of 5 to 8 weak rays parallel with caudal peduncle. Vertebrae 104-109. *Desmodema*, new genus.
- 7a. Gill rakers 40-58. Premaxilla set at right angle to frontal profile, maxilla horizontally ovate. Gastric caecum extends well past anus. Color pattern of irregular oblique stripes and polka-dots. *Regalecus*.
- 7b. Gill rakers 8-10. Premaxilla continues forward in line with frontal profile, maxilla vertically ovate. Gastric caecum ends before anus. Color pattern banded. *Agrostichthys*.

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KEYS TO THE FRESHWATER AND ANADROMOUS FISHES OF CALIFORNIA¹

J. B. KIMSEY

Inland Fisheries Branch
California Department of Fish and Game

LEONARD O. FISK²

California Department of Water Resources

The need for keys to all the freshwater and anadromous fishes of California long has been apparent to both scientific workers and laymen. Although numerous keys to California fishes have been published, they have been either restricted to certain drainages (i.e., Miller, 1952; Murphy, 1941; Rutter, 1908) or to groups of fishes (i.e., Beland, 1953; Curtis, 1949; Neale, 1931; Robins and Miller, 1957; Shapovalov, 1947).

The first check list of the freshwater and anadromous fishes of California (Shapovalov and Dill, 1950) listed 101 full species, of which 65 were native species and 26 introduced species. The second check list (Shapovalov, Dill, and Cordone, 1959), issued nine years later, contains 11 species and 7 subspecies not listed in 1950. Six species and one subspecies resulted from introductions into fresh water. Two freshwater and three euryhaline species, and three euryhaline subspecies were added by new collecting or more complete examination of old collections. Three subspecies resulted from taxonomic revisions.

The rate of addition to our fish fauna is somewhat less than that to our avian fauna, and it is unlikely that all North American fish species will some day occur in California, as Grinnell (1922) postulated for birds. It is apparent, however, that the Californian fish fauna is losing its unique character at an accelerated rate. About 18 successful introductions were made prior to 1900. In the first 50 years of this century, nine additional introductions were made, and seven more have been made in the ten years since 1950. It is evident that these keys will need to be revised at intervals, and that, in the interim between revisions, it will be possible to collect fish that cannot be keyed out with them.

The keys are designed to aid people in knowing what California freshwater or euryhaline fish they have in hand. There is no intention to satisfy the needs of the professional taxonomist, although his work is the stuff from which keys are made. Microscopic examination or complicated statistical comparison is unnecessary. We have tried to limit the use of internal key characters to pharyngeal teeth and pyloric caeca counts. A hand lens will be useful.

Several of the minnow and sucker genera contain subspecies that are difficult to differentiate. In these instances the description is accompanied by the original geographic range. Many native minnows have been

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² Formerly with Inland Fisheries Branch, California Department of Fish and Game.

widely transported as bait and may now occur well outside their original range. An extreme example of this was the collection in 1954 of a Sacramento hitch, *Lavinia e. exilicauda*, from Ramer Lake, Imperial County, approximately 320 road miles south of its regular range.

ACKNOWLEDGMENTS

We have drawn freely upon others for ideas both from published and unpublished material. The former sources are well covered in the accompanying bibliography.

The keys in their original mimeographed form were widely circulated for testing and criticism. Among those who took advantage of this opportunity for revision and comment were Reeve M. Bailey, John P. Harville, Robert R. Miller, George S. Myers, and Thomas L. Rodgers. In most instances, their suggested changes were made. We do not mean to imply, however, that they are in full agreement with our treatment.

For anatomical terms, counts, and methods of measurements (Figure 1) we have only occasionally departed from Hubbs and Lagler (1958). We have followed Shapovalov, Dill, and Cordone (1959) in common and scientific names.

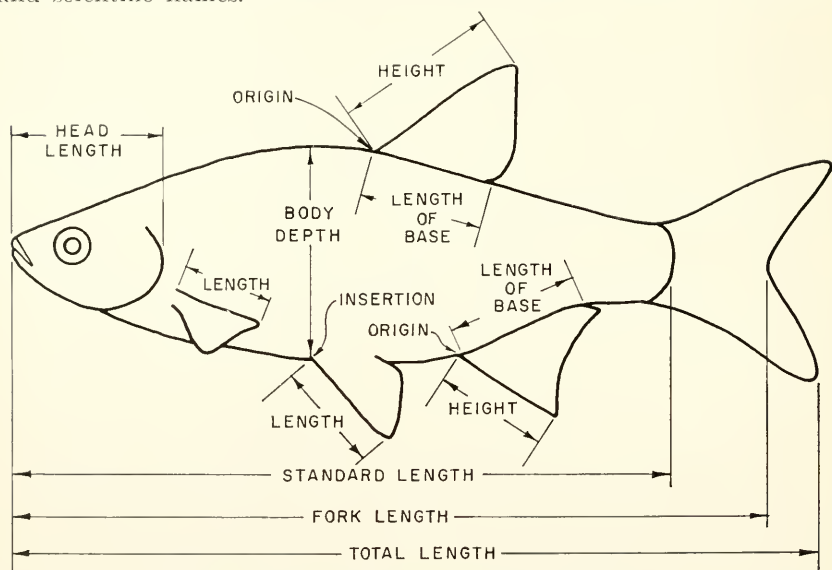


FIGURE 1. Methods of measurements used in the key.

HOW TO USE THE KEYS

These keys are based on alternative characters. For instance, the user finds himself initially confronted with a choice between two characters, 1a and 1b. If the description under 1b fits the fish in hand, he is referred to 2, where a choice between 2a and 2b occurs. This process continues until the fish is identified. At that point a more complete description is given.

Counts and Terms

Technical language has been kept to a minimum. However, a glossary of terms has been included. Figure 2 illustrates a hypothetical bony fish with the more common anatomical terms illustrated.

Scale counts are usually listed in the following manner: 10 to 12—54 to 60—6 or 7. The first figures, 10 to 12, are the number of scale rows above the lateral line. This count is taken from the origin of the dorsal fin downward, following the natural scale row to, but not including, the lateral line scale. The next figures, 54 to 60, represent the number of scales in the lateral series. This is either the number of scales bearing pores in the lateral line or those in the position of a normal lateral line. The scales actually on the base of the caudal fin are not counted. The third set of figures, 6 or 7, represent the scales below the lateral line. The count is made upwards and forward from the origin of the anal fin to, but not including, the scale in the lateral line.

The scale count before the dorsal fin to the occiput is occasionally used. All the scales intercepted by the midline from the origin of the dorsal fin to the edge of the scaleless occiput region are counted.

Gill raker counts indicate the number on the whole first arch on the left side.

In pyloric caeca counts, all tips are included.

Pharyngeal teeth counts are made upon dissection and cleansing of the modified fifth gill arch. A formula 2,5-5,2 means the left pharyngeal bone has 2 teeth in the outer row and 5 in the inner row (2,5); 5 teeth in the inner row and 2 teeth in the outer row of the right side (5,2). A formula 5-4 indicates one row of teeth on each bone, the left bone having 5 teeth and the right 4. Care should be taken that the alveoli or holes where teeth are missing are also included in the count. Individual pharyngeal teeth are frequently shed or lost in cleaning.

Fin rays, when spines occur, are indicated by a combination of Roman and Arabic numerals. The Roman numerals (I, II, III, etc.) represent the number of spines, while the Arabic numerals (1, 2, 3, etc.) represent soft rays. If the spinous rays and soft rays are in the same fin, the numerals are separated by a comma (1, 3).

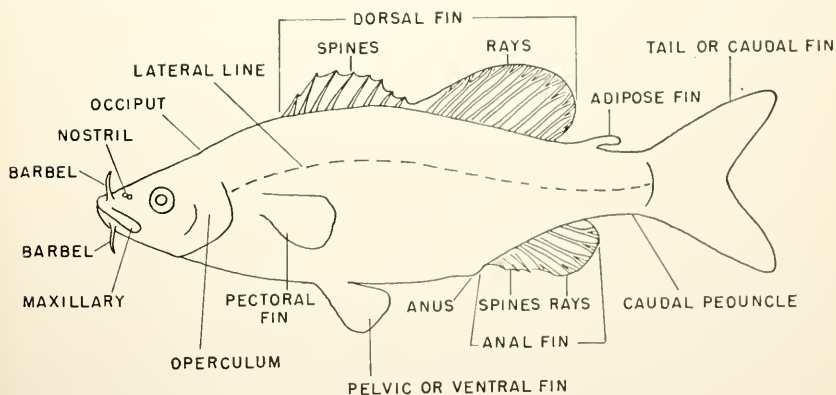


FIGURE 2. Diagram of a hypothetical fish, showing anatomical features used in the key.

KEY TO FAMILIES

- 1a. Mouth a sucking disc; 7 gill openings on each side of head. Figure 3 ----- PETROMYZONTIDAE—lamprey family, page 463

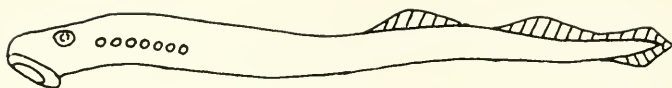


FIGURE 3. Petromyzontidae

- 1b. Mouth with true jaws; 4 gill openings covered by operculum ____ 2
 2a. Body with 5 rows of large bony shields, each with a large keel or spine; caudal fin lobes unequal. Figure 4 -----
 ----- ACIPENSERIDAE—sturgeon family, page 463

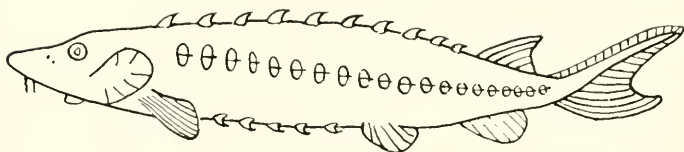


FIGURE 4. Acipenseridae

- 2b. Body without rows of plates; caudal fin lobes equal or nearly so ----- 3
 3a. Body extremely flattened laterally; both eyes on same side of head; coloring on one side of body only. Euryhaline. Figure 5 -----
 ----- PLEURONECTIDAE—righteyed flounder family.
 ----- Starry flounder, *Platichthys stellatus* (Pallas)

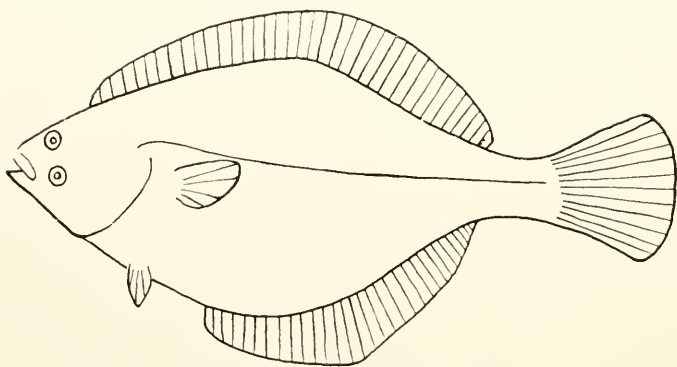


FIGURE 5. Pleuronectidae

- 3b. Characters not as above. ----- 4
 4a. Dorsal fin preceded by 3 free spines. Figure 6 -----
 ----- GASTEROSTEIDAE—stickleback family.
 ----- Threespine stickleback, *Gasterosteus aculeatus* Linnaeus

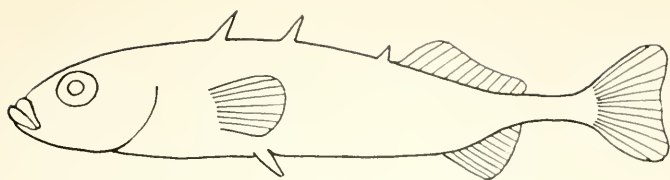


FIGURE 6. Gasterosteidae

- 4b. Dorsal fin not preceded by free spines, all spines present connected by membranes..... 5
- 5a. Gular plate (Figure 27) present between branches of lower jaw. Euryhaline. Figure 7. ELOPIDAE—ladyfish family.
 ----- Machete; *Elops affinis* Regan

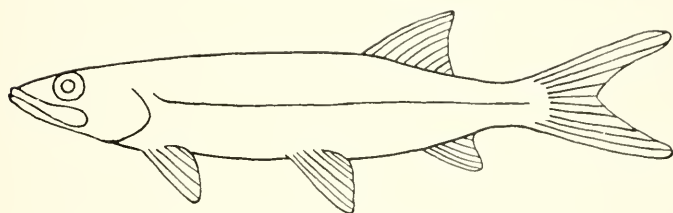


FIGURE 7. Elopidae

- 5b. Gular plate absent..... 6
- 6a. Body without scales..... 7
- 6b. Body with scales (one exception in Cyprinidae)..... 8
- 7a. Chin with barbels; adipose fin present. Figure 8.....
 ----- ICTALURIDAE—catfish family, page 471

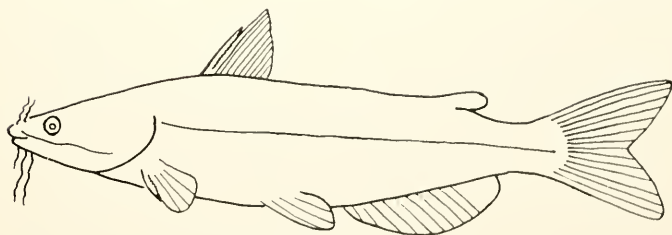


FIGURE 8. Ictaluridae

- 7b. Chin without barbels; no adipose fin. Figure 9.....
 ----- COTTIDAE—sculpin family, page 474

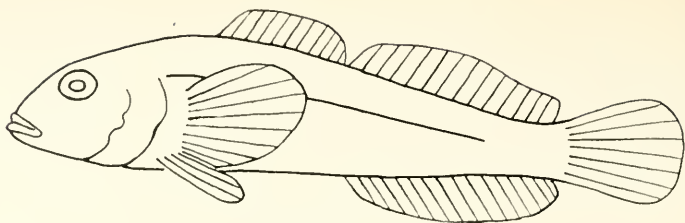


FIGURE 9. Cottidae

8a. Pelvic fins united, forming a sucking disc. Figure 10-----
 -----GOBIIDAE—goby family, page 474

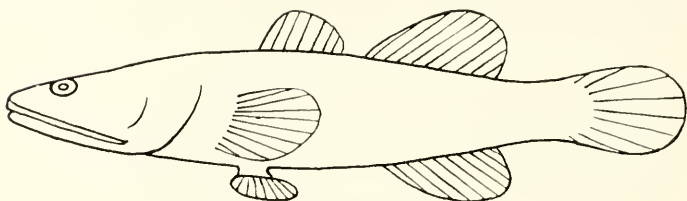


FIGURE 10. Gobiidae

- 8b. No abdominal sucking disc----- 9
 9a. Adipose fin present----- 10
 9b. Adipose fin absent----- 12
 10a. Scales small, more than 100 in lateral series. Figure 11-----
 -----SALMONIDAE—salmon and trout family, page 464

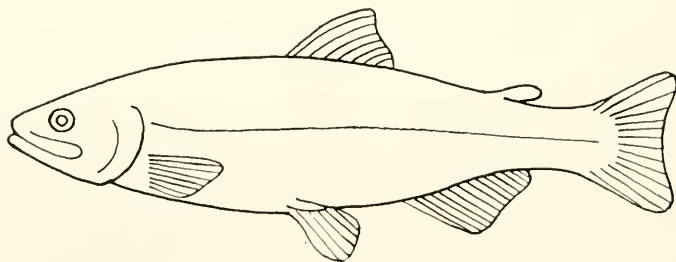


FIGURE 11. Salmonidae

- 10b. Scales larger, fewer than 100 in lateral series----- 11
 11a. Teeth strong; maxillaries extending behind middle of eye; no appendage above base of pelvic fin. Euryhaline. Figure 12-----
 -----OSMERIDAE—smelt family, page 464

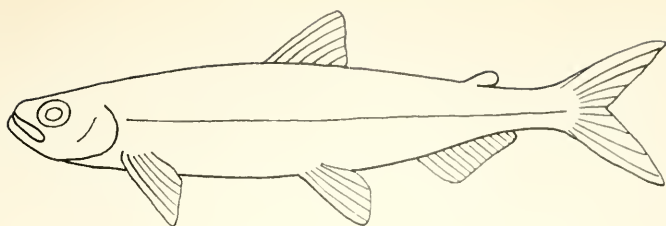


FIGURE 12. Osmeridae

11b. Teeth weak or absent; maxillaries not extending behind middle of eye; scaly appendage above base of pelvic fin. Figure 13

----- COREGONIDAE—whitefish family

----- Mountain whitefish, *Coregonus williamsoni*, Girard

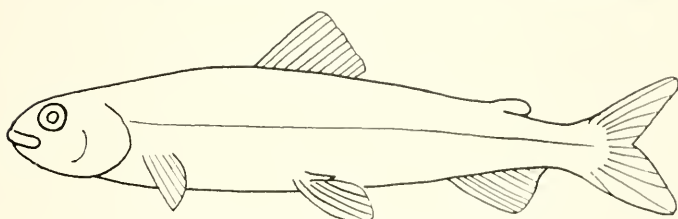


FIGURE 13. Coregonidae

12a. Belly with strong, spiny scutes, like a saw edge. Figure 14

----- CLUPEIDAE—herring family, page 464

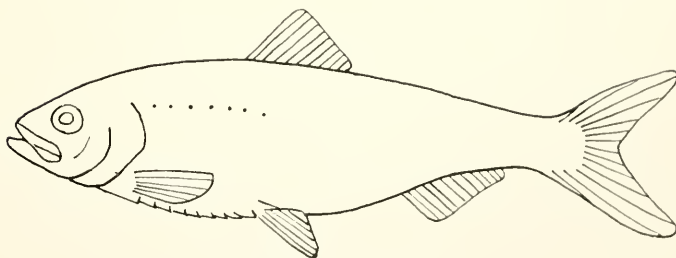


FIGURE 14. Clupeidae

12b. Belly without scutes ----- 13

13a. Caudal fin rounded ----- 14

13b. Caudal fin forked or square, not rounded ----- 16

14a. Dorsal fin with both spines and rays. Colorado River. Euryhaline. Figure 15 ----- ELEOTRIDAE—sleeper family

----- Spotted sleeper, *Eleotris picta*, Kner and Steindachner

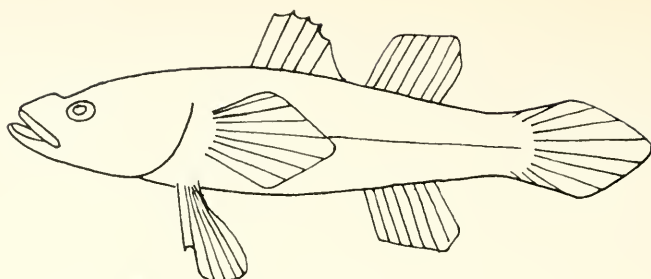


FIGURE 15. Eleotridae

14b. Dorsal fin without spines, composed of rays only

- 15a. Anal fin of male modified into an intromittent organ; third anal ray unbranched; bear live young. Figure 16.

----- POECILIIDAE—topminnow family, page 472

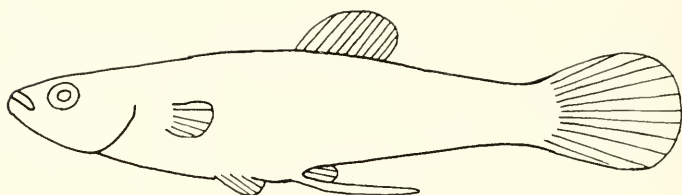


FIGURE 16. Poeciliidae

- 15b. Anal fin of male not modified; third anal ray branched; not live-bearers. Figure 17.

----- CYPRINODONTIDAE—killfish family, page 471

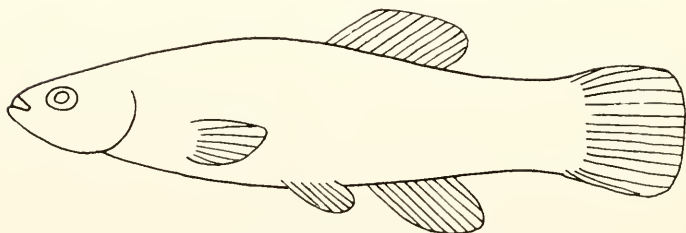


FIGURE 17. Cyprinodontidae

16a. Pelvic fins abdominal----- 17

16b. Pelvic fins thoracic----- 19

- 17a. Dorsal fin separated; stomach gizzard-like; anal spines 3. Euryhaline. Figure 18.

----- MUGILIDAE—mullet family.

----- Striped mullet, *Mugil cephalus* Linnaeus

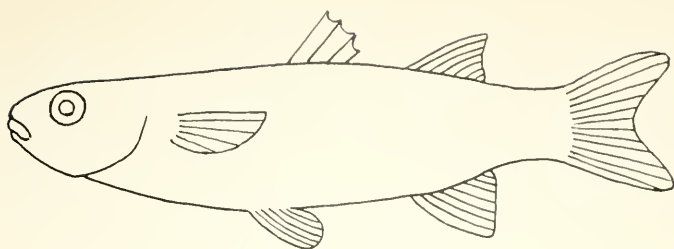


FIGURE 18. Mugilidae

17b. Dorsal fin not separated; stomach not gizzard-like; not more than one anal spine..... 18

18a. Mouth fitted for sucking; lips usually thickened and covered with wart-like skin; pharyngeal teeth numerous and usually comb-like. Figure 19.

-----CATOSTOMIDAE—sucker family, page 466

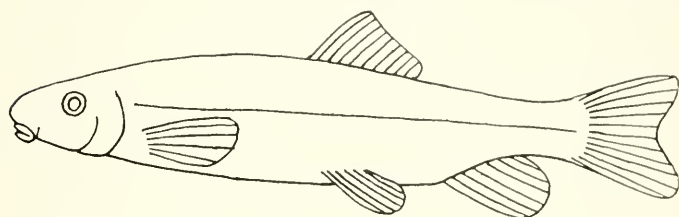


FIGURE 19. Catostomidae

18b. Mouth not fitted for sucking; lips thin, never wart-like; pharyngeal teeth fewer than 9 on each side. Figure 20.

-----CYPRINIDAE—carp or minnow family, page 468

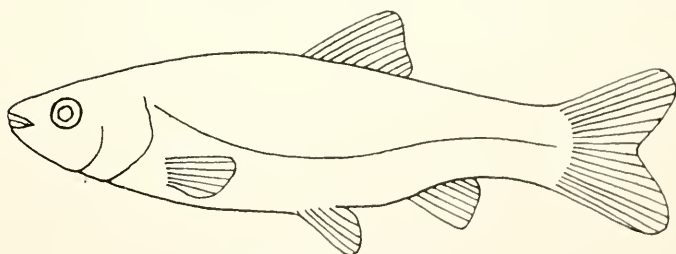


FIGURE 20. Cyprinidae

19a. Dorsal fin entirely separated or but slightly joined together..... 20

19b. Dorsal fin united..... 22

20a. Anal spines 3; body with narrow longitudinal stripes. Figure 21.

-----SERRANIDAE—bass family.

-----Striped bass, *Morone saxatilis* (Walbaum)

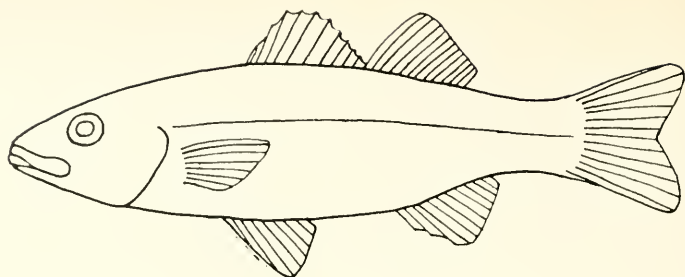


FIGURE 21. Serranidae

- 20b. Anal spines 1 or 2; body without longitudinal stripes..... 21
 21a. Anal spines 2; pelvic fins thoracic. Figure 22.....
 -----PERCIDAE—perch family, page 472

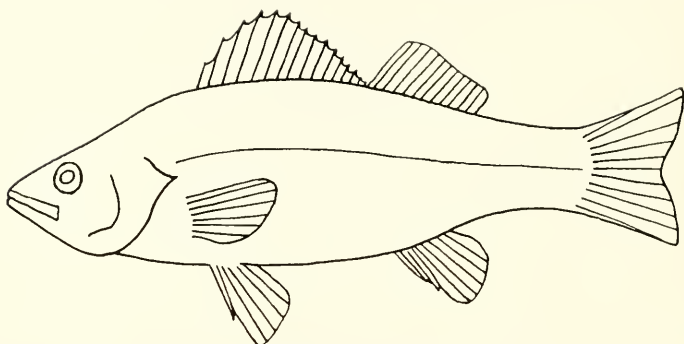


FIGURE 22. Percidae

- 21b. Anal spine 1; pelvic fins abdominal. Euryhaline. Figure 23.....
 -----ATHERINIDAE—silverside family.
 -----Topsmelt, *Atherinops affinis* (Ayres)

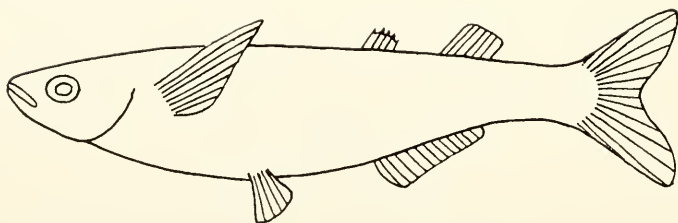


FIGURE 23. Atherinidae

- 22a. Dorsal fin with distinct ridge of scales along base; bear live young. Figure 24.....
 -----EMBIOTOCIDAE—viviparous perch family, page 474

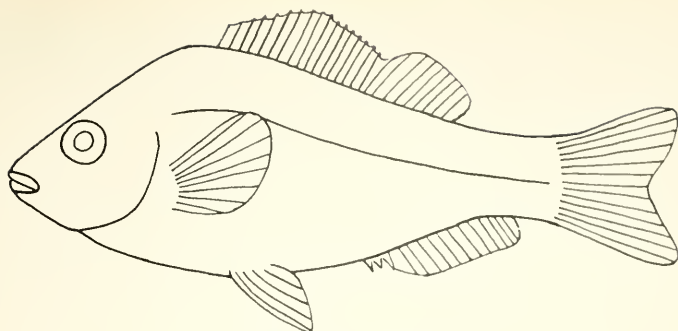


FIGURE 24. Embiotocidae

- 22b. Dorsal fin without distinct ridge of scales along base; not live-bearers. Figure 25.

-----CENTRARCHIDAE—sunfish family, page 472

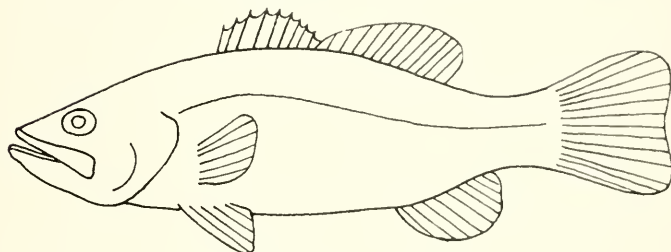


FIGURE 25. Centrarchidae

KEYS TO SPECIES

Family PETROMYZONTIDAE

- 1a. A posterior series of small teeth present parallel to the marginal series and connecting the last pair of enlarged laterals; usually 4 enlarged laterals
-----Pacific lamprey, *Entosphenus tridentatus* (Richardson)
- 1b. No teeth other than the marginals on the posterior field of the disc; 3 enlarged laterals ----- 2
- 2a. Dorsal fins usually well separated by an interspace; all teeth sharp and strong; parasitic -----
-----River lamprey, *Lampetra ayresii* (Günther)
- 2b. Dorsal fins separated only by a notch to base; all teeth weak and blunt; nonparasitic -----
-----Brook lamprey, *Lampetra planeri* (Bloch)

Family ACIPENSERIDAE

- 1a. Dorsal rays 44 to 53; anal rays 28 to 32; 4 barbels in a transverse row nearer the tip of snout than the mouth; 38 to 48 bony shields in lateral series on each side of the body; gill rakers 23 to 30 -----
-----White sturgeon, *Acipenser transmontanus* Richardson

- 1b. Dorsal rays 33 to 40; anal rays 21 to 31; 4 barbels in a transverse row nearer the mouth than the tip of the snout; 23 to 31 bony shields in lateral series on each side of the body; gill rakers 15 to 19 ----- Green sturgeon, *Acipenser medirostris* Ayres

Family CLUPEIDAE

- 1a. Dorsal fin with last ray greatly elongated; stomach gizzard-like; one dark spot behind opercle. Introduced ----- Threadfin shad, *Dorosoma petenense* (Günther)
- 1b. Dorsal fin without long ray; stomach muscular but not gizzard-like ----- 2
- 2a. Several dark spots behind opercle; head length much less than body depth. Introduced ----- American shad, *Alosa sapidissima* (Wilson)
- 2b. No dark spots behind opercle; head length not notably less body depth. Euryhaline ----- Pacific herring, *Clupea pallasii* Valenciennes

Family OSMERIDAE

- 1a. Pelvic fins inserted under or behind middle of dorsal; mouth small, maxillary not reaching beyond middle of pupil; pectoral fins small ----- 2
- 1b. Pelvic fins inserted in front of middle of dorsal; mouth large, maxillary reaching posterior edge of pupil; pectoral fins large. 3
- 2a. Scales 66 to 76 in lateral series; pectoral fins scarcely reaching half way to pelvics. Euryhaline ----- Surf smelt, *Hypomesus pretiosus* (Girard)
- 2b. Scales 56 to 60 in lateral series; pectoral fins reaching two-thirds distance to pelvics. Euryhaline ----- Pond smelt, *Hypomesus olidus* (Pallas)
- 3a. Canine teeth present on vomer (Figure 31); scales firmly attached; pectoral fins not reaching insertion of pelvics. Klamath River northward. Euryhaline ----- Eulachon, *Thaleichthys pacificus* (Richardson)
- 3b. No canine teeth on vomer; scales loosely attached; pectoral fins large, reaching insertion of pelvics. Euryhaline ----- Sacramento smelt, *Spirinchus thaleichthys* (Ayres)

Family SALMONIDAE

- 1a. Anal fin elongate, 13 to 19 rays (rarely 12); gill rakers 19 to 40 on first arch (Figure 30); branchiostegals 12 to 19; mouth blackish in adults ----- 2
- 1b. Anal fin short, 9 to 12 rays (rarely 13); gill rakers 20 or fewer on first arch; branchiostegals 10 to 12; mouth whitish in adults. 6
- 2a. Scales very small, 170 to 232 in lateral series; parr marks absent in young ----- Pink salmon, *Oncorhynchus gorbuscha* (Walbaum)

- | | |
|---|----|
| 2b. Scales larger, less than 160 in lateral series | 3 |
| 3a. Gill rakers long, 30 to 50; parr marks in young small, often oval or rounded, largely above lateral line | |
| ----- Sockeye salmon (anadromous form); | |
| Kokanee salmon (freshwater form), <i>Oncorhynchus nerka</i> (Walbaum) | |
| 3b. Gill rakers short, 20 to 28 | 4 |
| 4a. Scales usually 19 to 26 above, and usually 15 to 24 below the lateral line; parr marks faint, not rounded, mostly above lateral line | |
| ----- Chum salmon, <i>Oncorhynchus keta</i> (Walbaum) | |
| 4b. Scales usually 25 to 31 above, and usually 23 to 34 below the lateral line; parr marks in young extending below lateral line | 5 |
| 5a. Anal rays usually 15 to 17; pyloric caeca 140 to 150; entire mouth black in adults; young with parr marks wider than interspaces | |
| ----- King salmon, <i>Oncorhynchus tshawytscha</i> (Walbaum) | |
| 5b. Anal rays usually 12 to 15; pyloric caeca 50 to 83; gums whitish; young with parr marks narrower than interspaces | |
| ----- Silver salmon, <i>Oncorhynchus kisutch</i> (Walbaum) | |
| 6a. Less than 190 scales in lateral series; dark spots on lighter background; vomer (Figure 31) flattened, with teeth on shaft | 7 |
| 6b. More than 190 scales in lateral series; red or gray spotted on darker background; vomer trough-like, with a toothless shaft | 10 |
| 7a. Body with distinct parr marks throughout life in stream forms (lake forms lose parr marks at end of first year); a yellowish-orange band on lateral line grading into yellow farther down and finally orange on the abdomen; young lake forms (under 10 inches) not possessing parr marks, having instead of typical golden trout color a rather diffuse rosy tinge on a silvery background | |
| ----- Golden trout, <i>Salmo aguabonita</i> Jordan | |
| 7b. Characters not as above | 8 |
| 8a. Caudal fin not spotted; a few red or brown spots on sides; back covered with brown spots; color on back and sides yellowish or greenish brown. Introduced. | |
| ----- Brown trout, <i>Salmo trutta</i> Linnaeus | |
| 8b. Body often profusely spotted with black; no red or brown spots on sides; back and sides darker; caudal fin covered with spots | 9 |
| 9a. Red dash usually along inner edge of dentary bone; small teeth present on basibranchial plate. | |
| ----- Cutthroat trout, <i>Salmo clarkii</i> Richardson | |
| 9b. No red dash; no teeth on basibranchial plate; a rosy lateral band usually present. | |
| ----- Rainbow trout, <i>Salmo gairdnerii</i> Richardson | |

- 10a. Caudal fin rather strongly forked; vomer with a raised crest armed with strong teeth; pyloric caeca 95 to 170; no bright spots. Introduced.-----
 ----- Lake trout, *Salvelinus namaycush* (Walbaum)
- 10b. Caudal fin little forked; vomer without crest, the teeth being confined to the head of the bone; pyloric caeca 20 to 46; red or orange spots on sides.----- 11
- 11a. Back unspotted but strongly mottled with olive and black; caudal and dorsal fins marbled. Introduced.-----
 ----- Eastern brook trout, *Salvelinus fontinalis* (Mitchill)
- 11b. Back not mottled but with light spots like those on sides of body, only paler; caudal and dorsal fins not marbled.-----
 ----- Dolly Varden trout, *Salvelinus malma* (Walbaum)

Family CATOSTOMIDAE

- 1a. Mouth terminal, oblique; lips thin, without papillae----- 2
- 1b. Mouth inferior; lips thick, with papillae----- 4
- 2a. Gill rakers short, without tufts on edges and shaped like the Greek letter Delta Δ ; snout with pronounced hump.-----
 ----- Lost River sucker, *Deltistes luxatus* (Cope)
- 2b. Gill rakers long, may be acutely triangular but unlike Greek letter Delta; no hump on snout.----- 3
- 3a. Dorsal fin elongate, more than 25 rays. Introduced.-----
 ----- Bigmouth buffalo, *Ictiobus cyprinella* (Valenciennes)
- 3b. Dorsal fin short, fewer than 20 rays; gill rakers with edges densely tufted.----- Shortnose sucker, *Chasmistes brevirostris* Cope
- 4a. Pronounced sharp-edged hump in adults anterior to dorsal fin; median cleft of lower lip deep, separating halves completely. Colorado River.-----
 ----- Humpback sucker, *Xyrauchen texanus* (Abbott)
- 4b. No sharp-edged hump anterior to dorsal fin.----- 5
- 5a. Both jaws with broad, flattened, horny, cutting edges; deep V indentations at junctions of upper and lower lips, median indentation of lower lip not reaching the margin of the lower jaw (Figure 26A).----- 6



FIGURE 26. Characteristic shape of sucker mouths. A, *Pantosteus*; B, *Catostomus*.

- 5b. No well-developed cutting edge on either jaw; lower lip evenly joined to upper, no indentations or only slight ones at lateral junctions of lips, median indentation of lower lip reaching margin of jaw or nearly so (Figure 26B).----- 7

- 6a. Closed fontanelle; scales in lateral series 74 to 80. Santa Ana River and other southern California waters draining into the Pacific Ocean. _____
 --- Santa Ana mountain-sucker, *Pantosteus santaanae* Snyder
- 6b. Open fontanelle; scales in lateral series 84 to 95. Lahontan drainage and North Fork Feather River. _____
 ----- Lahontan mountain-sucker, *Pantosteus lahontan* Rutter
- 7a. More than 80 scales in lateral series. _____ 8
- 7b. Less than 80 scales in lateral series. _____ 11
- 8a. Lower lip not deeply incised, so that two or more rows of papillae extend across the symphysis. Klamath River drainage. _____
 ----- Klamath smallscale sucker, *Catostomus rimiculus* Gilbert and Snyder
- 8b. Lower lip deeply incised, so that not more than one row of papillae extends across the symphysis. _____ 9
- 9a. Body slender, fusiform, with an especially slender caudal peduncle; free margin of dorsal fin concave; unusually large lower lip divided to base. Colorado River, rare. _____
 ----- Flannelmouth sucker, *Catostomus latipinnis* Baird and Girard
- 9b. Body heavier, not fusiform, caudal peduncle moderately thick; one row of papillae extending across symphysis. _____ 10
- 10a. Fontanelle closed or at most represented by a narrow slit in specimens 6 inches long or over. Pit River drainage. _____
 ----- Modoc sucker, *Catostomus microps* Rutter
- 10b. Fontanelle present throughout life. Lahontan drainage, introduced into parts of the Sacramento River system, such as the upper Feather River and the Rubicon River. _____
 ----- Tahoe sucker, *Catostomus tahoensis* Gill and Jordan
- 11a. Species of the Klamath River drainage; scales 13 or 14—69 to 77—10 or 11, scales before dorsal fin about 32; caudal peduncle deep; not common. _____
 ----- Klamath largescale sucker, *Catostomus snyderi* Gilbert
- 11b. Species of the Russian River and the Sacramento-San Joaquin drainage. Scales 13 to 17—62 to 72—10 to 12, scales before dorsal 31 to 38; pectoral fins pointed. _____ Sacramento western sucker, *Catostomus occidentalis occidentalis* Ayres
- 11c. Species of the Goose Lake, Modoc County, drainage; scales 13 to 17—62 to 75—8 to 10, scales before dorsal fin 29 to 36. _____ Goose Lake western sucker, *Catostomus occidentalis lacusanserinus* Fowler
- 11d. Species of the Eel River, Bear River (Humboldt County), and Mad River; scales 11 to 14—62 to 69—8 to 10, scales before dorsal fin 27 to 34; pectoral fins rounded; mouth larger than *C. o. occidentalis*. _____ Humboldt sucker, *Catostomus humboldtianus* Snyder
- 11e. Species of streams tributary to Monterey Bay; scales 10 to 13—57 to 63—8 to 10, scales before dorsal fin 23 to 31. _____
 ----- Monterey sucker, *Catostomus mniotiltus* Snyder

Family CYPRINIDAE

- 1a. Dorsal fin with 1 or 2 spines..... 2
- 1b. Dorsal fin without spines..... 4
 - 2a. First two dorsal rays modified as smooth spines, the anterior with a groove on the posterior side into which the second fits; no scales
Woundfin, *Platypterus argentissimus* Cope
 - 2b. Only first dorsal ray modified as a strong serrate spine..... 3
- 3a. Upper jaw with 2 barbels on each side. Introduced.....
Carp, *Cyprinus carpio* Linnaeus
- 3b. Upper jaw without barbels. Introduced.....
Goldfish, *Carassius auratus* (Linnaeus)
- 4a. A fleshy scaleless keel on abdomen between pelvic and anal fins. Introduced.....
Golden shiner, *Notemigonus crysoleucas* (Mitchill)
- 4b. No fleshy keel on fully-scaled abdomen..... 5
- 5a. Scales in lateral series 100 or more..... 6
- 5b. Scales in lateral series 90 or less..... 7
 - 6a. Upper jaw with one barbel on each side. Introduced.....
Tench, *Tinca tinca* (Linnaeus)
 - 6b. Upper jaw without barbels.....
Sacramento blackfish, *Orthodon microlepidotus* (Ayres)
- 7a. Anal rays usually 10 to 14, dorsal rays 10 to 13; body laterally compressed..... Hitch, *Lavinia exilicauda* Baird and Girard 8
- 7b. Anal rays usually 6 to 9 (rarely 10)..... 9
 - 8a. Species of the Pajaro and Salinas River drainages; scales 12 to 14-54 to 60-6 or 7, scales before dorsal fin 31 to 35; dorsal fin rays 10 (8 to 12), anal fin rays 10 (8 to 13).....
Monterey hitch, *Lavinia exilicauda harengus* Girard
 - 8b. Species of the Sacramento-San Joaquin River drainage and the Russian River; scales 12 to 14-57 to 62-6 or 7, scales before dorsal fin 35 to 38; dorsal fin rays 11 (10 to 12), anal fin rays 13 (11 to 14).....
Sacramento hitch, *Lavinia exilicauda exilicauda* Baird and Girard
- 9a. Premaxillaries bound to snout by a frenum (Figure 29).....
Hardhead, *Mylopharodon conocephalus* (Baird and Girard)
- 9b. No frenum, premaxillaries protractile, separated from snout by a groove..... 10
 - 10a. Upper jaw barbel well developed; upper lobe of caudal fin considerably longer than lower.....
Splittail, *Pogonichthys macrolepidotus* (Ayres)
 - 10b. Upper jaw barbel absent; upper and lower lobes of caudal fin approximately equal..... 11
- 11a. Less than 45 scales in lateral series..... 12

- 11b. More than 45 scales in lateral series 13
- 12a. Lateral line incomplete; adults with horizontal dark bar across dorsal fin; scales crowded before dorsal fin. Introduced Fathead minnow, *Pimephales promelas* Rafinesque
- 12b. Lateral line complete; dorsal fin without dark bar; scales not crowded before dorsal fin. Introduced Red shiner, *Notropis lutrensis* (Baird and Girard)
- 13a. Body slender, pike-like; snout long and pointed 14
- 13b. Body not pike-like; snout shorter 15
- 14a. Anal fin rays 9. Colorado river drainage Colorado River squawfish, *Ptychocheilus lucius* Girard
- 14b. Anal fin rays 7 or 8. Sacramento-San Joaquin and Russian River drainages and tributaries of San Francisco and Monterey bays Sacramento squawfish, *Ptychocheilus grandis* (Ayres)
- 15a. Pharyngeal teeth in two rows 16
- 15b. Pharyngeal teeth in one row 22
- 16a. Mouth inferior; barbel on upper jaw; radii present on all fields of the scale 17
Speckled dace, *Rhinichthys osculus* (Girard)
- 16b. Mouth terminal; no barbel on upper jaw; radii present only on the apical and/or lateral fields of the scale 18
- 17a. Species of the Lahontan drainage; scales 12 to 14—56 to 77—9 to 11 Lahontan speckled dace, *Rhinichthys osculus robustus* (Rutter)
- 17b. Species of the Sacramento-San Joaquin River drainage and most Pacific Ocean drainages in California; scales in lateral series 49 to 77 Pacific speckled dace, *Rhinichthys osculus carringtonii* (Cope)
- 17c. Species of the Klamath River drainage; scales in lateral series 60 to 81 Klamath speckled dace, *Rhinichthys osculus klamathensis* (Evermann and Meek)
- 17d. Species of the Death Valley drainage in California; scales in lateral series about 65 Nevada speckled dace, *Rhinichthys osculus nevadensis* Gilbert
- 18a. Scales crowded before dorsal; dark lateral band between two lighter bands. Lahontan redbelly, *Richardsonius creggii* (Girard)
- 18b. Scales not crowded before dorsal; coloration not as above 19
- 19a. Origin of dorsal fin slightly behind origin of pelvic fins 20
- 19b. Origin of dorsal fin above origin of pelvic fins 21
- 20a. Caudal peduncle extremely slender; dorsal fin rays 10 or 11, anal fin rays 9 to 11; scales in lateral series 75 to 85. Colorado River drainage Bonytail chub, *Gila robusta* Baird and Girard

- 20b. Caudal peduncle moderately thick; dorsal fin rays 8 (7 to 9), anal fin rays 7; scales in lateral series 52 to 63. Southern California streams tributary to the Pacific; may be introduced elsewhere -----
 ----- Arroyo chub, *Gila oreuttii* (Eigenmann and Eigenmann)
- 21a. Dorsal fin rays 8, anal fin rays 7 to 9; scales in lateral series 60 to 70; caudal peduncle moderately thick. Klamath River drainage -----
 ----- Klamath chub, *Gila bicolor* (Girard)
- 21b. Dorsal fin rays 8, anal fin rays 8; scales in lateral series 50 to 56; caudal peduncle nearly as deep as long; caudal fin only slightly broader than caudal peduncle. Sacramento-San Joaquin River drainage -----
 ----- Thicktail chub, *Gila crassicauda* (Baird and Girard)
- 22a. Origin of dorsal fin over or before insertion of pelvies; scales before dorsal fin 23 to 33 -----
 ----- Tui chubs, *Siphateles* 23
- 22b. Origin of dorsal fin behind insertion of pelvies; scales before dorsal fin 32 to 38. ----- 24
- 23a. Species of the Klamath River drainage; scales 10 to 12—43 to 54—5 to 7, scales before dorsal fin 22 to 27; anal fin rays 7 or 8 -----
 ----- Klamath tui chub, *Siphateles bicolor bicolor* (Girard)
- 23b. Species of the Sacramento-San Joaquin River drainage; scales 10 to 13—44 to 54—5 to 7, scales before dorsal fin 22 to 28; anal fin rays 7 to 9, dorsal fin rays 9; gill rakers on first arch 13 to 20 -----
 ----- Sacramento tui chub, *Siphateles bicolor formosus* (Girard)
- 23c. Species of the Lahontan drainage; scales 12 to 16—50 to 60—7 or 8, scales before dorsal fin 27 to 33; anal fin rays 7 or 8, dorsal fin rays 8; gill rakers on first arch 8 to 20 -----
 ----- Coarseraker tui chub, *Siphateles bicolor obesus* (Girard)
- 23d. Species of the Lahontan drainage; scales 13 to 15—57 to 63—7 or 8, scales before dorsal fin 29 to 33; anal fin rays 8, dorsal fin rays 8; gill rakers on first arch 29 to 36 -----
 ----- Fineraker tui chub, *Siphateles bicolor pectinifer* (Snyder)
- 23e. Species of the Mojave River drainage; scales 11 to 13—46 to 55—7 or 8, scales before dorsal fin 23 to 30; anal fin rays 7 or 8, dorsal fin rays 8 to 10; gill rakers on first arch 18 to 29 -----
 ----- Mojave chub, *Siphateles mohavensis* Snyder
- 24a. Species of the Sacramento-San Joaquin River drainage; scales 12 or 13—47 to 57—6 to 8, scales before dorsal fin 30; anal fin rays 8 or 9, dorsal fin rays 8 to 10; gill rakers on first arch 8 to 10, short, blunt -----
 ----- Sacramento western roach, *Hesperoleucus symmetricus symmetricus* (Baird and Girard)
- 24b. Species of streams tributary to Monterey Bay; scales 12 to 16—51 to 57—7 or 8, scales before dorsal 27 to 32; anal fin rays 7 or 8, dorsal fin rays 7 or 8; gill rakers on first arch 9, short, blunt -----
 ----- Monterey western roach, *Hesperoleucus symmetricus subditus* Snyder

- 24c. Species of streams tributary to Goose Lake, Modoc County; scales 12 to 15—54 to 61—8, scales before dorsal 32 to 38; anal fin rays 7, dorsal fin rays 8; gill rakers on first arch 8 or 9, short, blunt; peritoneum black to dusky
-----Northern roach, *Hesperoleucus mitchellii* Snyder
- 24d. Species of the Russian River and streams tributary to San Francisco Bay; scales 13—50 to 63—7, scales before dorsal fin 30, anal fin rays 8, dorsal fin rays 9; gill rakers on first arch 10, short, pointed, widely spaced. The eye is smaller and the head shorter than the other species; ventral fins rounded, not reaching anal
-----Venus roach, *Hesperoleucus venustus* Snyder
- 24e. Species of the Navarro River system, Mendocino County; scales 11 to 14—51 to 59—7, scales before dorsal fin 30; anal fin rays 8, dorsal fin rays 8; gill rakers on first arch 8, very short, blunt; tips of ventrals reach anus
-----Navarro roach, *Hesperoleucus navarroensis* Snyder
- 24f. Species of the Gualala River system, Sonoma County; scales 14 to 16—54 to 59—7 or 8, scales before dorsal fin 32; anal fin rays 7 or 8, dorsal fin rays 8; gill rakers on first arch 8, very short, blunt; ventrals reach anus when depressed, edges rounded
-----Gualala roach, *Hesperoleucus parvipinnis* Snyder

FAMILY ICTALURIDAE

- 1a. Caudal fin forked ----- 2
- 1b. Caudal fin square or rounded ----- 3
- 2a. Anal fin short, 19 to 23 rays; no dark spots present on sides. Introduced ----- White catfish, *Ictalurus catus* (Linnaeus)
- 2b. Anal fin long, 24 to 29 rays; dark spots often present on sides, especially in juveniles and nonbreeding adults. Introduced ----- Channel catfish, *Ictalurus punctatus* Rafinesque
- 3a. Anal rays 24 to 27; caudal fin rounded; chin barbels whitish. Introduced ----- Yellow bullhead, *Ictalurus natalis* (LeSueur)
- 3b. Anal rays 17 to 24; caudal fin square-cut; chin barbels gray to black ----- 4
- 4a. Pectoral spines with strong barbs on posterior edge; fin rays and membranes of same color; gill rakers 11 to 14 on first arch. Introduced ----- Brown bullhead, *Ictalurus nebulosus* (LeSueur)
- 4b. Pectoral spines with weak barbs; fins generally with jet black membranes; gill rakers 16 to 18 on first arch. Introduced ----- Black bullhead, *Ictalurus melas* (Rafinesque)

Family CYPRINODONTIDAE

- 1a. Teeth all pointed, none of them compressed, bicuspid or tricuspid.
-----California Killifish, *Fundulus parvipinnis* Girard

- 1b. Teeth incisor-like, notched, bicuspid, or tricuspid 2
- 2a. Pelvic fin rays 7-7; pelvic fins large, always present; dorsal fin equidistant between caudal base and tip of snout 3
- 2b. Pelvic fin rays 6-6; pelvic fins small, occasionally lacking; dorsal fin nearer caudal base than tip of snout 4
- 3a. Scale circuli with spine-like projections; interspaces between circuli without conspicuous reticulations; central cusp of tricuspid teeth spatulate
 ----- Desert pupfish, *Cyprinodon macularius* Baird and Girard
- 3b. Scale circuli without projections; interspaces between circuli densely reticulated; central cusp truncate
 ----- Owens Valley pupfish, *Cyprinodon radiosus* Miller
- 4a. Scales small, 28 or 29 in lateral series, 39 or 40 around body; outer face of tricuspid teeth with prominent, median ridge
 ----- Salt Creek pupfish, *Cyprinodon salinus* Miller
- 4b. Scales large, 25 or 26 in lateral series, 24 around body; no median ridge on tricuspid teeth Nevada
 pupfish, *Cyprinodon nevadensis* Eigenmann and Eigenmann

Family POECILIIDAE

- 1a. Origin of dorsal fin well behind that of anal fin; dorsal fin rays 7 to 9. Introduced
 ----- Mosquitofish, *Gambusia affinis* (Baird and Girard)
- 1b. Origin of dorsal over or before that of anal; dorsal fin rays 13 to 16. Introduced Sailfin molly, *Mollienesia latipinna* LeSueur

Family PERCIDAE

- 1a. Preopercle not strongly serrated; mouth small; body crossed with 9 to 15 primary bands, with shorter secondary bars alternating. Introduced Log perch, *Percina caprodes* (Rafinesque)
- 1b. Preopercle strongly serrated; mouth large 2
- 2a. No canine teeth; body crossed with 6 to 8 strong vertical bands; anal fin with 6 to 8 soft rays. Introduced.
 ----- Yellow perch, *Perca flavescens* (Mitchill)
- 2b. Strong canine teeth; body may be blotched but not crossed by vertical bars; anal fin with 12 to 14 soft rays. Introduced.
 ----- Walleye, *Stizostedion vitreum* (Mitchill)

Family CENTRARCHIDAE

- 1a. Anal spines 5 or more; branchiostegal rays 7 2
- 1b. Anal spines 3; branchiostegal rays 6 4
- 2a. Dorsal fin spines 12 or 13; dorsal fin base about twice length of anal fin base.
 ----- Sacramento perch, *Archoplites interruptus* (Girard)
- 2b. Dorsal fin spines 5 to 8; dorsal fin base about equal to anal fin base. 3

- 3a. Dorsal fin spines normally 7 or 8; length of dorsal fin base about equal to distance from origin of dorsal fin to eye; body more definitely banded. Introduced.-----
----- White crappie, *Pomoxis annularis* Rafinesque
- 4a. Scales small, 58 or more in lateral series; body depth about one-third standard length.----- 5
- 4b. Scales large, 53 or fewer in lateral series; body depth about one-half standard length.----- 7
- 5a. Dorsal fin almost divided; anal and soft dorsal fin with no scales on membrane near base; mouth large, upper jaw extending beyond eye in adults; sides of young and small adults with dark, rather even lateral band. Introduced.-----
----- Largemouth bass, *Micropterus salmoides* (Lacépède)
- 5b. Dorsal fin not deeply notched; anal fin and soft dorsal fin with scales on membrane near base; mouth moderate, upper jaw not extending beyond eye in adults; lateral band, if present, always broken.----- 6
- 6a. Predorsal contour generally flat; scales in lateral series 60 to 68; broken lateral band of blotches always present. Introduced.-----
----- Spotted bass, *Micropterus punctulatus* (Rafinesque)
- 6b. Predorsal contour rounded; scales in lateral series 69 to 80; sides of young and small adults with vertical bars or broad blotches with light centers, lacking in adults. Introduced.-----
----- Smallmouth bass, *Micropterus dolomieu* Lacépède
- 7a. Teeth present on tongue. Introduced.-----
----- Warmouth, *Chaenobryttus gulosus* (Cuvier)
- 7b. No teeth on tongue.----- 8
- 8a. Upper jaw extending to middle of eye; pectoral fin short and rounded, contained about four times in standard length. Introduced.-----
----- Green sunfish, *Lepomis cyanellus* Rafinesque
- 8b. Upper jaw not extending nearly to middle of eye; pectoral fins long and pointed, contained about three times in standard length.----- 9
- 9a. Opercular bone flexible posteriorly; gill rakers long and slender. Introduced.-----
----- Bluegill, *Lepomis macrochirus* Rafinesque
- 9b. Opercular bone stiff behind; gill rakers short and stout.----- 10
- 10a. Opercle with definite scarlet spot; cheeks with prominent blue and orange stripes in life; pectoral fins less than one-third standard length in adult. Introduced.-----
----- Pumpkinseed, *Lepomis gibbosus* (Linnaeus)
- 10b. Opercle with broad scarlet margins; cheeks without conspicuous orange and blue streaks; pectoral fins more than one-third standard length in adult. Introduced.-----
----- Red-ear sunfish, *Lepomis microlophus* (Günther)

Family EMBIOTOCIDAE

- 1a. Dorsal spines 10 or less. Euryhaline

Shiner perch, *Cymatogaster aggregata* Gibbons
- 1b. Dorsal spines 15 or more. Freshwater

Tule perch, *Hysteroecarpus traskii* Gibbons

Family COTTIDAE

- 1a. Upper preopercular spine antler-like, long, with recurved barbs along its upper margin. Euryhaline

Staghorn sculpin, *Leptocottus armatus* Girard
- 1b. All peropercular spines small, simple, inconspicuous ----- 2
- 2a. Palatine teeth absent ----- 3
- 2b. Palatine teeth present ----- 4
- 3a. Lateral line complete or nearly so; pelvic fins long, when depressed reach anus

Aleutian sculpin, *Cottus aleuticus* Gilbert
- 3b. Lateral line very incomplete; pelvic fins shorter. Klamath River

Klamath sculpin, *Cottus klamathensis* Gilbert
- 4a. Pelvic rays I, 3 ----- 5
- 4b. Pelvic rays I, 4 (spine may be embedded in first ray) ----- 6
- 5a. Area between dorsal fins and lateral line entirely naked or with only minute prickles. Euryhaline

Sharpnose sculpin, *Clinocottus acuticeps* (Gilbert)
- 5b. Area from pectoral fin to a point under the second dorsal covered with prickles

Rough sculpin, *Cottus asperimus* Rutter
- 6a. Skin entirely smooth

Piute sculpin, *Cottus beldingii* Eigenmann and Eigenmann
- 6b. Skin with prickles ----- 7
- 7a. Skin entirely covered with prickles; vent midway between base of caudal fin and tip of snout; dorsal rays 17 to 20; caudal vertebrae 24 to 27

Prickly sculpin, *Cottus asper* Richardson
- 7b. Skin with prickles restricted to region behind pectorals; vent nearer base of caudal fin than tip of snout; dorsal rays 16 to 18; caudal vertebrae 21 to 24

Rifle sculpin, *Cottus gulosus* (Girard)

Family GOBIIDAE

- 1a. Maxillaries normal; skull short and abruptly broadened behind orbits. Euryhaline

Tidewater goby, *Eucyclogobius newberryi* (Girard)
- 1b. Maxillaries extended backward, to beyond the gill opening in adult; skull comparatively long and gradually (not abruptly) broadened behind orbits ----- 2

- 2a. Occiput depressed, with a blunt median keel; dorsal fin VI, 12 or 13; anal fin 10 or 11. Euryhaline.....
 Longjaw mudsucker, *Gillichthys mirabilis* Cooper
- 2b. Occiput transversely rounded without median keel; dorsal fin IV or V, 14 to 17; anal fin 16 or 17. Euryhaline.....
 Arrow goby, *Clevelandia ios* (Jordon and Gilbert)

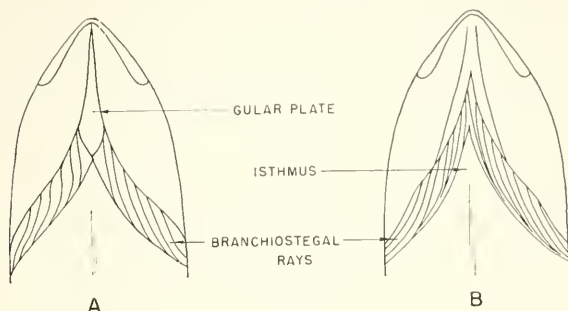


FIGURE 27. Diagram of the underside of the head of a fish. **A**, with a gular plate; **B**, without a gular plate.

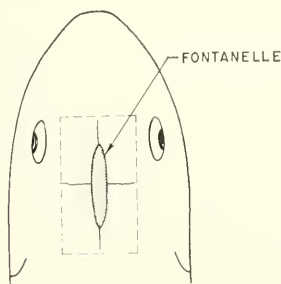


FIGURE 28. Diagram of the top of the head of a fish showing the position of the fontanelle when present.

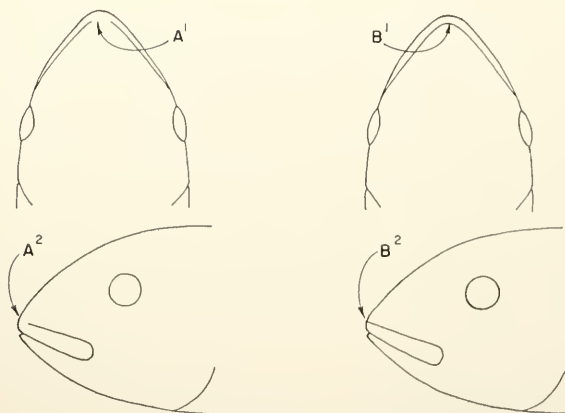


FIGURE 29. Diagram of fish heads. **A¹, A²**, with a frenum; **B¹, B²**, without a frenum.

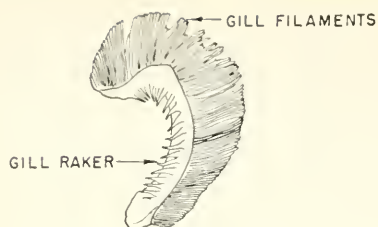


FIGURE 30. First gill arch taken from the left side showing gill rakers and gill filaments.

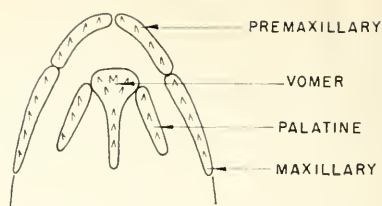


FIGURE 31. Diagram illustrating the tooth-bearing bones on the upper jaw and in the roof of the mouth.

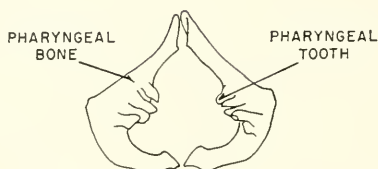


FIGURE 32. Diagram of the pharyngeal bones of a minnow.

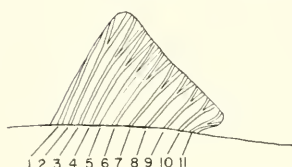


FIGURE 33. Diagram illustrating a soft-rayed fin and the method of counting rays.

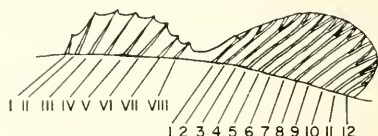


FIGURE 34. Diagram of the dorsal fin of a fish with both spines and soft rays illustrating method of counting. The formula in this instance would be VIII, 12.

GLOSSARY

Abdominal—Refers to the belly. Abdominal fins are also called ventral fins or pelvic fins. Figure 2.

Abdominal sucking disc—The pelvic fins united to form a flaring cone free from the body.

Adipose fin—The small, fleshy fin on the back, between the dorsal and caudal fin in some groups of fish. Figure 2.

Air bladder—A sac filled with gas, lying beneath the backbone and above the digestive tract.

Anal fin—The single fin on the median abdominal line behind the vent. Figure 2.

Apical—The posterior or exposed margin of a scale.

Basibranchial plate—The median bony structure (or rod or plate) on the floor of the throat.

Bicuspid—Top of tooth with two projections.

Branchiostegal rays—The bony rays supporting the gill membranes, under the lower jaw and between the lower portions of the opercular bones. Figure 27.

Barbel—A fleshy threadlike or conical projection usually about the mouth. The "whiskers" of catfish are barbels. Figure 2.

Caudal fin—The tail fin. Figure 2.

Caudal peduncle—The slender region between the end of the anal fin and the base of the caudal fin. Figure 2.

Compressed—Flattened laterally.

Circuli—Concentric ridges appearing as rings on the scales.

Concave—Hollow and curved or rounded.

Cusp—Apex or top of tooth.

Dentary bone—Anterior bone of the lower jaw.

Dorsal fin—The fin on the median line of the back. May be double. Figure 2.

Euryhaline—Species able to live extended periods in fresh, brackish, or salt water.

Fontanelle—An opening in a body surface. In some fish this refers to the area of cartilage in the mid-dorsal region of the skull. Figure 28.

Frenum—A bridge of tissue binding or restraining the apex of the upper jaw to the snout. Figure 29.

Fusiform—Spindle-shaped.

Gill arch—The bony arch to which the gills are attached. Figure 30.

Gill rakers—Slender, spine-like structures attached to the gill arches. Figure 30.

Gular plate—A large median dermal bone lying in the throat region. Figure 27.

Hypural plate—The expanded last vertebrae.

Incisor—A tooth adapted for cutting. Chisel-like rather than pointed.

Inferior mouth—Mouth on the under side of the head.

Insertion—The position at which a paired fin is joined to the body. Figure 1.

Intromittent organ—Copulatory organ; i.e., modified anal fin of poeciliid male.

Lateral line—A series of tubes and pores along the sides of a fish's body opening into sensory organs located beneath the scales. Figure 2.

Maxillaries—The bones of the upper jaw. The first bone on either side of the midline of the upper jaw is the premaxillary. The second bone is the maxillary. Figure 2.

Median—Situated on the midline of the fish; i.e., either the center of the back or center of the belly.

Oblique—Slanting, inclined; not horizontal.

Occiput—The back of the head; usually where the scales of the back stop. Figure 2.

Orbit—The eye socket.

Opercular bones—Gill cover bones. Figure 2.

Origin—The anteriormost extremity of the base of an unpaired fin. Figure 1.

Palatine teeth—Teeth on the paired bones of the roof of the mouth, just back of the vomer. Figure 31.

Papillac—Small fleshy protuberances.

Parr mark—Dusky vertical bars found on young trout and salmon.

Pectoral fins—The anterior or uppermost paired fins. Figure 2.

Pelvic fins—The paired fins attached to the pelvic girdle. The lowermost or rear paired fins. Figure 2.

Peritoneum—Interior lining of the body cavity.

Pharyngeal teeth—Teeth on the pharyngeal bones behind the gills in the throat. Figure 32.

Preopercular spine—A spine (or spines) on the cheekbone nearest the eye and next to the largest gill cover bone.

Protractile—Capable of being projected forward.

Pyloric caeca—Finger-like processes attached to the intestine where it leaves the stomach.

Radii—Lines on the scales extending from the center to the edge.

Ray—A supporting rod for a fin. They include segmented soft rays and unsegmented hard or spiny rays.

Reticulations—A series of web-like or network marks.

Scutes—Bony or horny plates.

Serrate—Notched or toothed on edge.

Spatulate—Spoon-shaped.

Spine—The unsegmented supports of the fin membranes, regardless of whether or not they are stiff.

Symphysis—The point where two bones join together in the median plane of the body (i.e., the two halves of the lower jaw at the chin).

Terete—Cylindrical in cross section.

Terminal mouth—Mouth in which neither the upper nor the lower jaw projects.

Thoracic—The chest region.

Tricuspid—Top of tooth with three projections.

Truncate—Square ended.

Ventral—Refers to the belly surface.

Ventral fins—See pelvic fins.

Viviparous—Brings forth the young alive.

Vomer—Middle palate-bone in the roof of the mouth. Figure 31.

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A WATERFOWL NESTING STUDY ON TULE LAKE AND LOWER KLAMATH NATIONAL WILDLIFE REFUGES, 1957¹

W. C. RIENECKER and WILLIAM ANDERSON
Game Management Branch
California Department of Fish and Game

INTRODUCTION

It has been planned to conduct waterfowl nesting studies on the major breeding areas in California at five-year intervals so that the data could be used to maintain comparative production records for the State.

An additional objective was to note any environmental changes that might have occurred since the 1952 nesting study (Miller and Collins 1953, 1954).

The present report covers a waterfowl nesting study which was conducted on Tule Lake and Lower Klamath National Wildlife Refuges during the spring and summer of 1957.

HISTORY

Tule Lake is located in Siskiyou County, California, just south of the Oregon border, at an elevation of approximately 4,000 feet. In the early 1900's the major portion of Lost River, Tule Lake's water source, was diverted causing Tule Lake to become almost dry. Much of the lake bed was reclaimed and today the area to the north and east of the refuge is highly valued agricultural land. On October 4, 1928, the lake was established as a wildlife refuge at the reduced size of 11,000 acres. The present size of the refuge is 35,337 acres. The water and marsh area is confined to two sumps totaling 12,880 acres, while the balance of the acreage is in leased farm lands, roads, canals, and dikes.

Lower Klamath National Wildlife Refuge is located just west of Tule Lake National Wildlife Refuge. The two refuges are separated by a low range of mountains known as Sheepy Ridge. On August 8, 1908, the Lower Klamath area was established as a refuge. The lake comprising much of this area was a natural sump as it was the lowest part of the Klamath Basin. The supply of water came from a channel leading south from the Klamath River. The water flowing in and out kept the lake and rivers at the same level. On November 10, 1917, the U.S. Reclamation Service, owing to the demand for additional agricultural lands, built a dike across the channel thereby drying the lake. Attempts were made to farm the lake bed but with little success. Eventually peat fires started and destroyed a good portion of the area. Since then the U.S. Fish and Wildlife Service has developed part of the area, re-

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storing it as one of the important waterfowl refuges in the United States. Water is controlled by pumping operations conducted by the Tule Lake Irrigation District under contract to the U.S. Bureau of Reclamation. The present size of the refuge is 28,188 acres of which 11,878 are open water and marsh.

The Canada goose (*Branta canadensis mollitti*) has been known to nest in the Lower Klamath Basin for many years. Information regarding the reproduction of this important game species was extremely sketchy in early publications describing the bird life of the region. Frank M. Chapman (1908) who visited Lower Klamath Lake from June 30 to July 7, 1906, made a brief mention of seeing a family of "wild geese" and later an adult of this species in the process of molting.

Harold C. Bryant (1914) conducted a survey of water birds during 1914 and camped at various locations in the vicinity of Tule Lake and Lower Klamath from June 1 to June 9. During that time he reported seeing three groups of Canada geese, adults and young, on the Lower Klamath area. Tule Lake was a vast body of water surrounded by lava beds and for the most part lacking favorable nesting habitat. However, he found evidence of nesting mallards (*Anas p. platyrhynchos*), redheads (*Aythya americana*), cinnamon teal (*Anas cyanoptera*), and ruddy ducks (*Oxyura jamaicensis rubida*). On Lower Klamath, Bryant listed five species of ducks: mallards, redheads, cinnamon teal, shovelers (*Spatula clypeata*), and ruddy ducks. However, neither Chapman's nor Bryant's reports indicate anything like the impressive breeding populations using these areas today.

METHODS

For all practical purposes the methods used in collecting the field data generally were the same as described in the 1952 studies (*op. cit.*). An additional method was used in relocating nests along the fringes of dense stands of cattail and hardstem bulrush. A marker was placed in open water where it was visible and a series of knots were tied in the vegetation leading from the marker to the nest. An alternate method to locate the trail from the marker to the nest site was used, and it consisted of spraying the vegetation with paint from a 12 ounce pressurized can.

Table 1 shows the size of the sample of nests for each species and the breeding population during the 1952 study as compared to this one. The difference in species composition as indicated in the table, could be due to a number of things such as increased development of the area, erosion of islands, formation of hardstem bulrush (*Scirpus acutus*) and cattail stands (*Typha latifolia*), and changes in water depths. The difference between the two studies in the size of the sample of nests for each species is due principally to a more intensive search for nests in fields of low vegetation and along dikes; in 1957 it also reflected the actual increase or decrease in a species.

TABLE 1
Sample Size and Breeding Populations in 1952 and 1957

Species	Estimated nesting population (pairs)		Number of nests in sample		Percent of nesting population in sample	
	1952	1957	1952	1957	1952	1957
Mallard	2,150	2,370	209	395	9.7	16.7
Gadwall	3,100	2,100	381	277	12.3	13.2
Widgeon	--	10	--	2	--	20.0
Pintail	400	916	44	216	11.0	23.6
Cinnamon teal	1,500	640	40	37	2.7	5.8
Shoveler	800	312	39	67	4.9	21.5
Redhead	3,000	2,770	60	94	2.0	3.4
Ruddy Duck	1,500	1,300	25	39	1.7	3.0
Lesser scaup	150	472	10	24	6.7	5.1
Total ducks	12,600	10,890	808	1,151	6.4	9.5
Canada goose	530	862	203	276	38.0	31.0
Coot	4,000	4,750	149	94	3.7	2.0

CANADA GOOSE

Nest Sites and Cover Types

The Canada goose phase of the waterfowl nesting study began on April 5 and was terminated on May 31, 1957 upon completion of the last nest history. The major portions of the marsh areas of Tule Lake and Lower Klamath were searched for goose nests. The nests were located by cruising along the edge of the marsh in an air-thrust boat, and by that means flushing the geese from their nests. Some dry land

TABLE 2
Comparison of Canada Goose Nest Sites in 1952 and 1957

Site	Number		Percent	
	1952	1957	1952	1957
Dike	12	21	6.0	7.9
Tule mat	21	123	10.4	46.0
Muskrat house	78	25	38.8	9.4
Island	76	94	37.8	35.2
Field	14	4	7.0	1.5
Total	201	267	100.0	100.0

areas on Lower Klamath such as dikes and islands were searched on foot, but the majority of the nests were located by use of the airboat. It is felt that enough nests were located to make a representative sample of nesting conditions throughout the areas.

The estimated nesting population was 230 pairs on Tule Lake, 624 pairs on Lower Klamath and eight pairs on White Lake. A total of 267 or 31 percent of all the nests on the three areas was studied: 43 or 19 percent of the nests on Tule Lake, 216 or 34.6 percent of the nests on Lower Klamath and eight or 100 percent on White Lake.

Five categories of nest sites used in Table 2 are described as follows:

Dike—All nests found on dikes, levees, ditch banks and the berm between ditch and dike.

Tule Mat—Nests found on heavy lodged growths of dead hardstem bulrush and, in a few cases cattail from previous years.

Muskrat House—Nests found on muskrat houses.

Island—All dry land areas not more than ten acres and completely surrounded by water. Islands of more than ten acres were recorded as fields.

Field—Any uncultivated land of a dry upland type.



FIGURE 1. Waterfowl habitat in Unit 2 on Lower Klamath National Wildlife Refuge. Photograph by A. W. Miller.

In the five years there had been an increased use of some areas for nesting such as Sheepy Lake (Figure 1) in Unit 2 on Lower Klamath and a decrease in others such as the Upper Sump of Tule Lake. There also had been a definite shift of nest sites from muskrat houses to tule

mats. In 1952, 38.8 percent of the nests were found on muskrat houses and 10.4 percent on tule mats, while in this study 9.4 percent were found on muskrat houses and 46.0 percent on tule mats. According to Fish and Wildlife Service inventories, 999 muskrat houses were counted on Tule Lake in 1952 and only 550 in 1956. This reduction in muskrat houses was the main cause for the shift. A preference for elevated nest sites that command a view of the surrounding cover, but with no regard for concealment, was noted in this as well as past Canada goose nesting studies in California.

In 1952, 34 percent of the nests found on islands were located on the Lower Sump. In the early 1930's 30 nesting islands were built on Tule Lake. They measured 360 feet long and approximately 40 feet wide on top, and projected four feet above the water level. Some of the islands had gravel on top and vegetation planted on the slopes to make them attractive to ducks and geese. Others were left barren as nesting islands for pelicans and gulls. By 1957 only one of these islands was left and it had eroded down to a few square yards. At the present time the only available nesting sites are in the tule fringe bordering the open water on the south and east sides. Erosion is also taking its toll of the natural islands on Lower Klamath and White Lake.

TABLE 3
Cover Types Utilized by Canada Geese in 1952 and 1957

Cover type	Number		Percent	
	1952	1957	1952	1957
Bulrush	95	137	47.2	51.3
Nettle	48	34	23.9	12.7
Saltbush	35	32	17.4	12.0
Cattail	6	18	3.0	6.7
Grasses	4	7	2.0	2.6
Mustard	1	1	0.5	0.4
Thistle	--	14	--	5.3
Bassia	--	5	--	1.9
Others	12	19	6.0	7.1
Total	201	267	100.0	100.0

Table 3 summarizes the data on the dominant vegetative types. Since the nesting season started well before the growing season, all but five nests were found in previous years' vegetation or in areas without cover. Forty-nine percent of the nests were over water and the remaining 51 percent were within 50 yards of water.

Fate of Nests

The fate of the nests is classified in five categories in Table 4: (1) hatched, (2) destroyed, (3) deserted, (4) flooded, and (5) unknown.

These classes are the same as those used in the 1952 study. There was little change between the fate of nests in the 1952 study and this one. The hatching success in 1952 was 78.6 percent compared to 78.7 percent in 1957.

TABLE 4
Fate of Canada Goose Nests in 1952 and 1957

Fate	Number		Percent	
	1952	1957	1952	1957
Hatched	158	210	78.6	78.7
Destroyed	5	19	2.5	7.1
Deserted	23	34	11.4	12.7
Flooded	10	4	5.0	1.5
Unknown	5	--	2.5	--
Total	201	267	100.0	100.0

Table 4 shows that there has been an increase of 4.6 percent in the number of nests destroyed during 1957 as compared with 1952. All but three of these nests were destroyed by birds. The only species of birds observed on the study areas which were known to destroy eggs were the California gulls (*Larus californicus*) and ring-billed gulls (*Larus delawarensis*). While an increase of 4.6 percent in nest predation does not appear to be significant, a large influx of gulls at some future date in the midst of favorable goose nesting could have serious consequences.

Nest failure due to desertion was 11.4 percent in 1952 as compared to 12.7 percent in 1957. It was the greatest single cause of nest failure in both studies. Overcrowding on preferred island sites was believed to be the main cause. In the work reported herein, 50 percent of the 34 deserted nests were found on islands.

Flooding, as a cause of nest failure, was of minor importance. Only 1.5 percent of the nests were flooded. In 1952 five percent of the nests failed from this cause. Of four flooded nests in 1957, two were on the Upper Sump and two on the Lower Sump of Tule Lake. During the winter the Tule Lake Irrigation District lowered the water level to safeguard against possible flood. When it became apparent that no flood would take place the water level was raised to normal and in the process flooded the four nests.

Fate of Eggs and Clutch Size

Only data obtained from successfully hatched nests was used in determining the fate of eggs and average clutch size. The 210 successful nests produced 1,147 eggs of which 1,001 or 87.2 percent hatched. Of the unhatched eggs 123 or 10.7 percent contained dead embryos and 11 or 1.0 percent were infertile. Six eggs were destroyed, five hatched but were found dead in the nest and one egg was missing. The clutch

size varied from one to 11 eggs with 62.3 percent of the clutches having five or six eggs (Table 5). The average clutch size was 5.5 eggs as compared to 5.1 in 1952. The average hatch was 4.8 in 1957 and 4.4 in 1952.

TABLE 5
Canada Goose Clutch Size in 1952 and 1957

	Number of eggs per nest											Total eggs	Average clutch
	1	2	3	4	5	6	7	8	9	10	11		
Nests 1952	1	4	14	23	53	47	11	3	1	1	--	810	5.1
1957	2	1	8	34	61	70	24	5	2	1	2	1,147	5.5
Percent 1952	0.7	2.5	8.8	14.5	33.5	29.7	7.0	1.9	0.7	0.7	--	100.0	
1957	1.0	0.5	3.8	16.2	29.0	33.3	11.3	2.4	1.0	0.5	1.0	100.0	

TABLE 6
Dates of Hatch for Canada Geese in 1952 and 1957 *

	April			May			June	Total
	2	12	22	2	12	22	2	
No. of nests 1952	--	1	66	73	16	2	--	158
1957	1	53	108	42	5	1	--	210
Percent 1952	--	0.6	41.8	46.2	10.1	1.3	--	100.0
1957	0.5	25.2	51.4	20.0	2.4	0.5	--	100.0

* Figures under each date are numbers of nests that have hatched prior to that date and after and including the preceding date.

Hatching Dates

The first clutch hatched between April 2 and 12. The first brood was observed on April 13. This would indicate the nesting season started about March 10. The last clutch hatched during the period of May 22 to June 2 and the last week old brood was recorded on May 29, therefore, the nesting season was about 79 days. Although 96.6 percent hatched during the 30 day period of April 12 to May 12 (Table 6), the peak of the hatch came between April 22 and May 2 or, approximately ten days earlier than in 1952.

No information concerning brood regression was recorded due to grouping of the broods. A number of young undoubtedly die during the first week of life from predation, accidents, becoming lost and other miscellaneous causes. On several occasions gulls were observed taking week old goslings.

DUCKS

Location and Description of Sample Areas

The study areas were set up for the purpose of obtaining a representative sample of all the species of ducks nesting on the refuges. The size of the plots was flexible, being governed by the maximum area that could be covered in one day. Diving duck nests were an exception, due to the difficulty in locating them, so additional acreage had to be covered

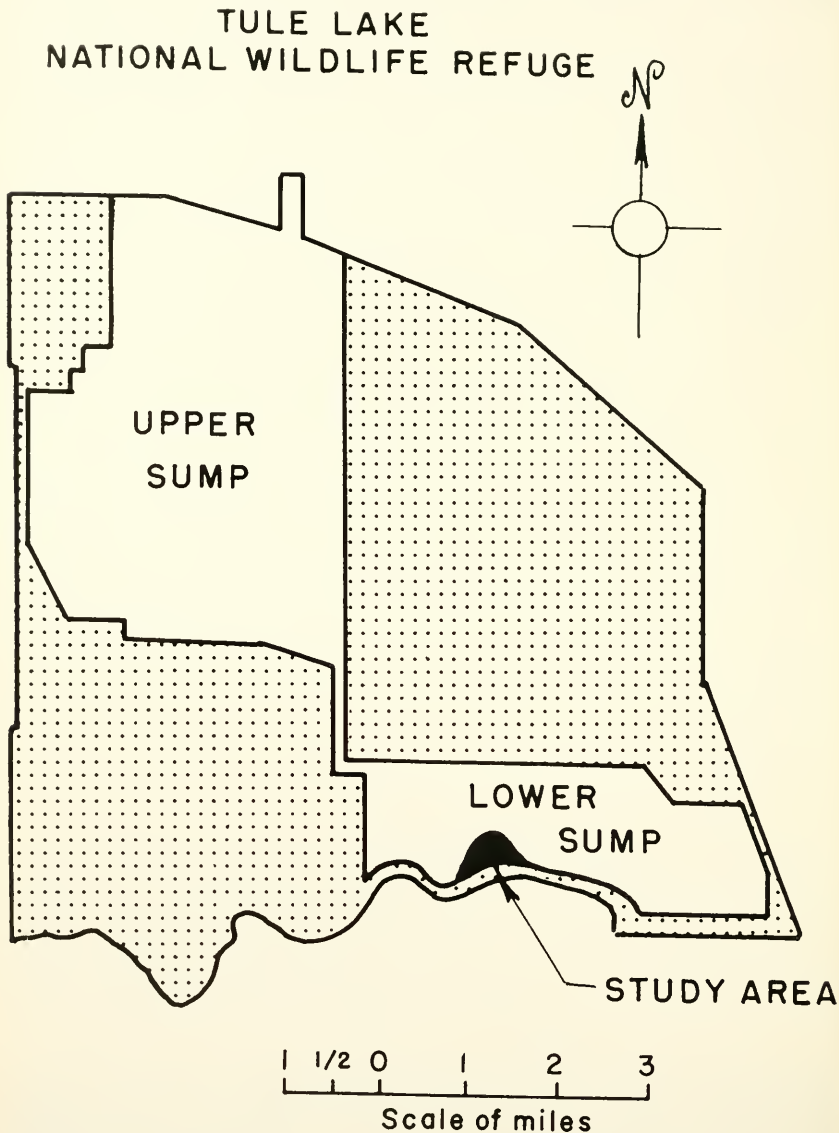


FIGURE 2. Study areas on Tule Lake National Wildlife Refuge. Shaded area is land.
Drawing by Cliffo Corson.

to obtain an adequate sample. The study areas were set up so that they could be covered in a ten day period. The locations of the area were similar to those of the 1952 study except for some additional acreage.

The Upper Sump of Tule Lake (Figure 2) contains 9,370 acres of which 75 percent is open water, one-half to four feet deep. The remaining 25 percent comprises emergent vegetation interspersed with pot-holes and channels. The emergents are hardstem bulrush, cattail and river bulrush (*Scirpus fluvialis*). After several unsuccessful attempts to locate duck nests in this area, the work was transferred to the Lower

LOWER KLAMATH NATIONAL WILDLIFE REFUGE

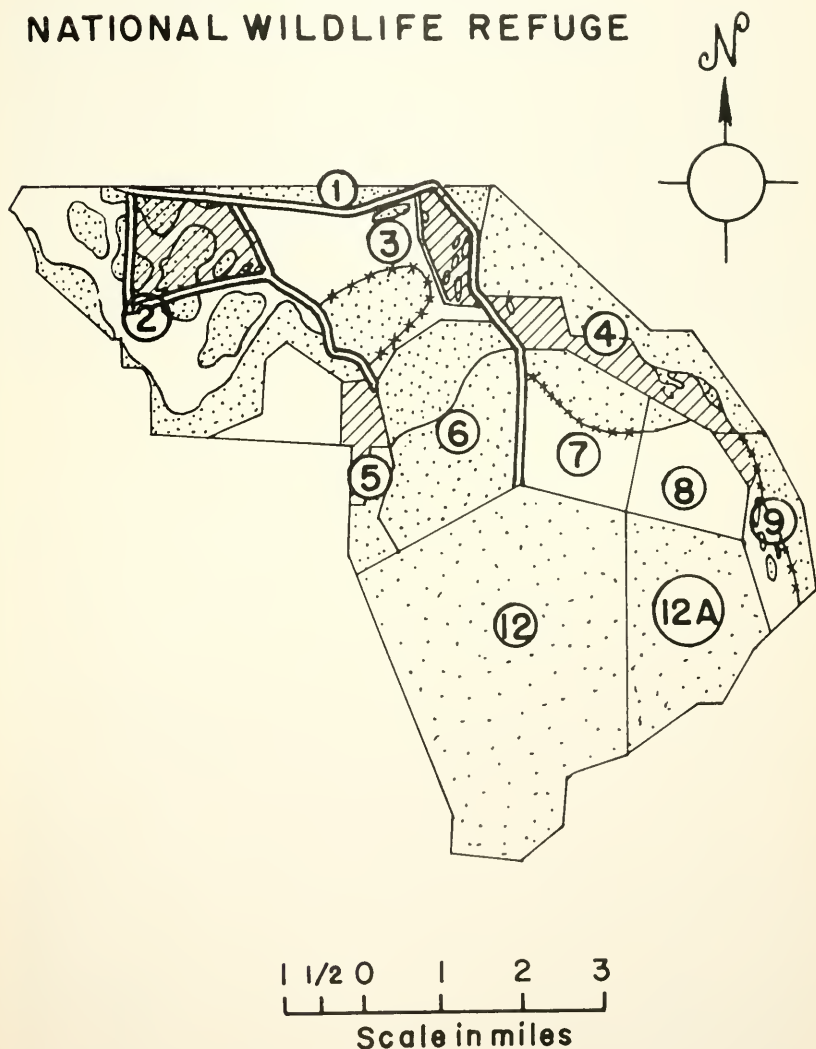


FIGURE 3. Study areas on Lower Klamath National Wildlife Refuge. Dotted area is land. Drawing by Cliffo Corson.



FIGURE 4. Waterfowl habitat in Unit 9 on Lower Klamath National Wildlife Refuge.
Photograph by A. W. Miller.

Klamath Refuge. The size of the study area bordering the south side of the Lower Sump of Tule Lake was 43 acres. It consisted of a belt of hardstem bulrush and cattail 10 to 50 yards in width on one side and dry upland vegetation composed of mustard and cheat grass (*Bromus tectorum*) on the other.

The greater portion of the study was conducted on Lower Klamath Refuge (Figure 3) where most of the waterfowl nesting occurred. The study area in the northeast part of Unit 2 comprised 545 acres of upland cover including nettle (*Urtica californica*), saltbush (*Atriplex* sp.) and foxtail barley grass (*Hordeum jubatum*); 155 acres of marsh, mainly patches of cattail and hardstem bulrush; and 200 acres of open water. The upland cover was on islands of less than one acre to 320 acres. The Unit 3 study area consisted of four and one-half miles of dike, bordered on one side by grain fields and on the other by upland type vegetation, a band of marsh 30 to 300 yards wide and open water. The dominant vegetation was five hooked bassia (*Bassia hyssopifolia*), foxtail barley grass and a few scattered patches of saltbush and nettle. Eight islands totaling 37 acres were included in the Unit 3 study area. The cover was composed of nettle with some foxtail barley grass and saltbush present. Four of the islands contained hardstem bulrush and cattail fringes. An additional 660 acres of marsh were searched at least once for redhead and ruddy duck nests.

Approximately 80 acres of islands and peninsulas plus three miles of dike and adjoining berm made up the Unit 4 study area. The cover consisted primarily of nettle, saltbush, mustard (*Sisymbrium* sp. and

Brassica sp.) and foxtail barley grass. The islands and peninsulas were spread throughout the 1,012 acres of water and marsh area of the unit with the dike forming the north boundary.

The Unit 5 study area was an uncultivated field of 235 acres. The dominant cover was foxtail barley grass and saltbush with some mustard. Two miles of dike and berm made up the Unit 7 study plot. The dike separated the water area from the field area of the unit. The vegetation was foxtail barley grass, saltbush and mustard. Several islands in the north part totaling about 10 acres and 2.3 miles of dike comprised the Unit 9 (Figure 4) study plot. The cover on the islands was nettle, saltbush, five hooked bassia and foxtail barley grass. The dike was the east boundary of the water area. The vegetation along the dike consisted mainly of saltbush and mustard with a few scattered patches of nettle and five hooked bassia.

The White Lake study area was located near the northeast corner of the Lower Klamath Refuge. Its extent was 1,154 acres of which 912 were in California and 242 were in Oregon. The lake was dotted with numerous islands varying from four acres to a few square yards. The principal cover on these islands was saltgrass (*Distichlis spicata*). Prior to 1954 it was important only as a grazing area. Since 1954 it was managed by the Fish and Wildlife Service as a waterfowl area with restrictions on grazing and with an effort made to stabilize the water level. The lake was included in the study because of its nesting potential. Forty duck nests and eight Canada goose nests were found during the study. This low occurrence of nests is due presumably to the absence of suitable nesting cover.

Nest Sites and Cover Types

The nest sites listed in Table 7 were described in the section on the Canada goose except for the marsh site. Nests located in emergent vegetation over water or semi-wet land were recorded as being on marsh sites.

In Table 7 mallards show a decrease in the use of marsh sites and an increase in field sites as compared to the 1952 study. These differences were not due to a shift in mallard nesting sites but due to a difference in sampling methods. No attempt was made to find nests in hardstem bulrush and cattail until after the diving ducks had begun to nest, which was well past the nesting peak for mallards. The increase in field nest sites was due to the increased acreage covered. On analyzing the two studies by nest per acre of comparable habitat no appreciable change had occurred.

The decrease in the use of mustard and nettle and the increased use of saltbush, thistle and grasses as a cover type in 1957 as compared to the 1952 study (Table 8) is thought to be due to the abnormal climatic conditions that prevailed during the spring of 1952. Nettle and, to a lesser extent mustard were the first new growths to appear in 1952, which presumably caused the heavy use by ducks, especially gadwall (*Anas strepera*). This heavy use of nettle as nesting cover was believed to be greater than normal, and its use in 1957 probably approximates the average annual use.

TABLE 7
Location of Nest Sites in 1952 and 1957

Species		Dike		Marsh		Island		Field		Total	
		No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Mallard	1952	54	25.9	41	19.7	69	33.1	45	21.3	209	100.0
	1957	112	28.4	10	2.5	150	38.0	123	31.1	395	100.0
Gadwall	1952	51	13.4	3	0.8	236	61.9	91	23.9	381	100.0
	1957	44	15.9	2	0.7	167	60.3	64	23.1	277	100.0
Widgeon	1952	--	--	--	--	--	--	--	--	--	--
	1957	--	--	--	--	--	--	2	100.0	2	100.0
Pintail	1952	3	6.7	--	--	14	31.8	27	61.4	44	100.0
	1957	31	14.4	--	--	78	36.1	107	49.5	216	100.0
Cinnamon teal	1952	8	20.0	8	20.0	17	42.5	7	17.5	40	100.0
	1957	6	16.2	6	16.2	20	54.1	5	13.5	37	100.0
Shoveler	1952	--	--	--	--	7	18.0	32	82.0	39	100.0
	1957	1	1.5	--	--	15	22.4	51	76.1	67	100.0
Redhead	1952	--	--	56	93.3	3	5.0	1	1.7	60	100.0
	1957	--	--	90	95.7	4	4.3	--	--	94	100.0
Ruddy duck	1952	--	--	25	100.0	--	--	--	--	25	100.0
	1957	--	--	39	100.0	--	--	--	--	39	100.0
Lesser scaup	1952	--	--	--	--	8	80.0	2	20.0	10	100.0
	1957	10	41.7	2	8.3	12	50.0	--	--	24	100.0
Total	1952	116	14.4	133	16.5	354	43.8	205	25.3	808	100.0
	1957	204	17.7	149	13.0	446	38.7	352	30.6	1151	100.0

The mallard showed no preference as to nest site but did prefer a medium to high cover type such as saltbush and nettle. The gadwall preferred island nest sites with fields a second choice. Nettle was still the preferred cover. The pintail (*Anas acuta*) showed a preference to fields with a medium to low cover type such as saltbush and grass. The cinnamon teal could be expected to be found in any type of habitat, although it showed a slight preference to islands with cover composed of nettles. The shoveler showed a definite preference to fields with low grass cover. The redhead and ruddy duck were found almost exclusively in marsh habitat with high cover such as roundstem bulrush and cattail. The lesser scaup (*Aythya affinis*) preferred a dry upland type habitat with a slight preference towards islands with nettles.

TABLE 8

Cover Types Utilized in 1952 and 1957

Species	Mustard		Saltbush		Nettle		Bassia		Typha		Thistle		Hardstem bulrush		Grass		Other		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Mallard	18 35	8.6 8.9	55 159	26.2 40.3	73 74	35.0 18.7	1 22	0.5 5.5	2 20	1.0 5.1	8 41	3.8 10.4	39 11	18.6 2.8	3 22	1.4 5.5	10 11	4.7 2.8	209 395	100.0 100.0
Gadwall	30 8	7.8 2.9	29 48	7.6 17.3	304 138	79.9 49.8	2 3	0.5 1.1	-- 6	-- 2.2	10 61	2.6 22.0	4 2	1.1 0.7	2 8	0.5 2.9	-- 3	-- 1.1	381 277	100.0 100.0
Widgeon	-- --	-- --	-- 1	-- 50.0	-- --	-- --	-- --	-- --	-- --	-- --	-- 1	-- 50.0	-- --	-- --	-- --	-- --	-- --	-- --	-- 2	-- 100.0
Pintail	13 8	29.5 3.7	7 70	15.9 32.4	12 26	27.4 12.0	1 6	2.3 2.8	-- 1	-- 0.5	2 27	4.5 12.5	-- 2	-- 0.9	4 63	9.1 29.2	5 13	11.3 6.0	44 216	100.0 100.0
Cinnamon teal	7 2	17.5 5.4	3 5	7.5 13.5	17 14	42.5 37.9	-- --	-- --	-- 2	-- 5.4	-- 2	-- 5.4	9 4	22.5 10.8	2 7	5.0 18.9	2 1	5.0 2.7	40 37	100.0 100.0
Shoveler	7 --	18.0 --	1 5	2.5 7.5	4 5	10.3 7.5	-- --	-- --	-- --	-- --	7 7	10.4 --	-- --	-- --	22 47	50.4 70.1	5 3	12.8 4.5	39 67	100.0 100.0
Redhead	-- --	-- --	-- 3	-- 3.2	1 --	1.7 --	-- --	-- --	3 22	5.0 23.4	-- --	-- --	55 68	91.6 72.3	-- 1	-- 1.1	1 --	1.7 --	60 94	100.0 100.0
Ruddy duck	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- 9	-- 23.1	-- --	-- --	24 30	96.0 70.9	-- --	-- --	1 --	4.0 --	25 39	100.0 100.0
Lesser scaup	-- 4	-- 16.7	1 3	10.0 12.5	4 8	40.0 33.3	-- --	-- --	-- --	-- --	-- --	-- --	-- 2	-- 8.3	5 7	50.0 29.2	-- --	-- --	10 24	100.0 100.0
Total-----1952 1957	75 57	9.3 4.9	96 294	11.9 25.5	415 265	51.5 23.1	4 31	0.5 2.7	5 60	0.6 5.2	20 139	2.4 12.1	131 119	16.2 10.3	38 155	4.7 13.5	24 31	2.9 2.7	808 1151	100.0 100.0

TABLE 9
Fate of Duck Nests in 1952 and 1957

Species	Hatched		Destroyed		Deserted		Flooded		Dead embryo		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Mallard	1952	178	85.2	8	3.7	7.7	6	3.4	--	--	209	100.0
	1957	316	80.0	38	9.6	9.9	--	--	2	0.5	395	100.0
Gadwall	1952	344	90.3	13	3.4	6.3	--	--	--	--	381	100.0
	1957	242	87.4	12	4.3	7.6	--	--	2	0.7	277	100.0
Widgeon	1952	--	--	--	--	--	--	--	--	--	--	--
	1957	2	100.0	--	--	--	--	--	--	--	2	100.0
Pintail	1952	41	93.2	2	4.5	2.3	--	--	--	--	44	100.0
	1957	196	90.8	12	5.6	2.7	--	--	2	0.9	216	100.0
Cinnamon teal	1952	32	80.0	1	2.5	10.0	3	7.5	--	--	40	100.0
	1957	28	75.7	4	10.8	13.5	--	--	--	--	37	100.0
Shoveler	1952	35	89.7	1	2.6	7.7	--	--	--	--	39	100.0
	1957	63	94.0	2	3.0	3.0	--	--	--	--	67	100.0
Redhead	1952	27	45.0	1	1.7	15.0	23	38.3	--	--	60	100.0
	1957	83	88.3	3	3.2	7.4	1	1.1	--	--	94	100.0
Ruddy duck	1952	8	32.0	1	4.0	24.0	10	40.0	--	--	25	100.0
	1957	27	69.2	1	2.6	23.1	2	5.1	--	--	39	100.0
Lesser scaup	1952	9	90.0	1	10.0	--	--	--	--	--	10	100.0
	1957	19	79.2	4	16.6	4.2	--	--	--	--	24	100.0
Total	1952	674	83.4	28	3.5	7.8	42	5.3	--	--	808	100.0
	1957	976	84.8	76	6.6	7.8	3	0.3	6	0.5	1151	100.0

Fate of Nests

Fate of nests was classified in five categories: (1) hatched, (2) destroyed, (3) deserted, (4) flooded, and (5) dead embryos, (Table 9). Definitions of the first four categories are the same as those published in the 1952 study. The fifth category concerned nests that were active with the hen incubating the eggs, all of which contained dead embryos. If the eggs of a nest had not hatched after several visits, at ten day intervals, the nest history was checked to determine if sufficient time had elapsed for the eggs to hatch. When it was found that ample time had passed, the eggs were opened and the fate determined.

Successful Nests

The average nesting success for all species of ducks found in 1952 and in 1957 was similar. In 1952, 83.4 percent of the duck nests had hatched eggs compared to 84.8 percent during this study. In making a comparison of nesting success by species in the two studies a wider range is found. The mallard, gadwall, pintail, cinnamon teal and scaup showed a reduction in nesting success, varying from 10.8 percent for the scaup to 2.5 percent for the pintail. The shoveler was the only dabbling duck that showed an increase in nesting success over the 1952 study with 89.7 percent success in 1952 as compared to 94.0 percent. The greatest difference in nesting success was among the redheads and ruddy ducks. In 1952 the redhead and ruddy duck success was 45.0 and 32.0 percent, respectively, and showed an increase to 88.3 and 69.2 percent. The two widgeon (*Marca americana*) nests found hatched successfully. None were found in 1952.

Unsuccessful Nests

Destruction

Although nest destruction by predators showed an increase from 3.5 percent in 1952 to 6.6 percent in this study, it did not influence the overall nesting success. In 1957, 38 percent of the destroyed nests were found on or alongside dikes as compared to 19.2 percent in 1952. This study contained 7.5 miles of dike more than the 1952 study areas. This could well be one of the reasons for apparent increase in nest destruction between the two studies.

Of the 40 nests destroyed by mammals, 16 were by striped skunks (*Mephitis mephitis*), a coyote (*Canis latrans*) ravaged one, and 23 were destroyed by unknown mammals. On or near three nests the hens were found dead. The striped skunk and coyote undoubtedly accounted for the nests that were classified as destroyed by unknown mammals but there was not enough evidence to point to a specific animal. There were large populations of both the California and ringbill gulls present on the study areas and at least 20 nests were destroyed by them. An additional eight nests had all eggs removed which was probably done by gulls. Six of the eight nests were on small islands in the White Lake area where no destruction was observed until after a large number of gulls moved into the area. Four nests did not contain enough clues to identify the predator. Two nests were stepped on, one nest was destroyed by a road grader and one was destroyed by fire.

Tule Lake Refuge contains a narrow margin of potential nesting cover along the south boundary, bordered by open water of the Lower Sump to the north and the Lava Beds National Monument on the south.

The monument consists of a rocky, dry, upland type of habitat suitable to skunks and coyotes. One of the purposes of the sample area on the south side of the Lower Sump was to determine if the high rate of nest destruction by mammals still prevailed. In 1952, 43 percent of the nests were destroyed on a six acre plot. In this study the plot was enlarged to 43 acres. A total of 12 nests were found and seven or 58 percent were destroyed. The skunks and coyotes that invade the refuge from the monument were responsible for this high rate of nest destruction. The constant influx of predators from the monument to the refuge makes predator control by trapping impractical. The high incidence of predation could have driven a portion of the nesting population to other areas. Comparable areas in other parts of the refuge with low nest destruction usually have a medium to high nest density. Although the nest destruction is high along the Lower Sump, the area is small and does not materially influence the over-all nesting success of Tule Lake and Lower Klamath Refuges.

Desertion

No change has taken place in the amount of desertion of duck nests since the 1952 study. Both studies showed the rate of desertion at 7.8 percent. By species the ruddy duck had the highest rate of desertion, 24.0 percent in 1952 and 23.1 percent in this study. Intraspecific and interspecific parasitism probably had much to do with the high rate of desertion. Thirty-three percent of the deserted ruddy duck nests contained redhead eggs whereas only 11 percent of the hatched ruddy duck nests contained redhead eggs.

Flooding

Nest destruction due to flooding was unimportant. Only three of the 1,151 duck nests were flooded. It was of major significance in 1952 among the redhead and ruddy duck nests on the Upper Sump of Tule Lake. Thirty-eight and three-tenths percent of the redhead nests and 40 percent of the ruddy duck nests were lost due to fluctuating water levels. The water level of Tule Lake during the nesting season of 1952 was held higher than normal, approximately two-tenths of a foot higher than during the 1957 season. This high water level plus strong winds, which caused both wave action and a pile up of water in the northeast corner of the Upper Sump were the principal factors involved in the high incidence of flooded nests among the redhead and ruddy ducks. Only nine duck nests were located on the Upper Sump during 1957, no flooding of nests was observed.

Dead Embryos

Nests with all eggs containing dead embryos were of minor significance. Two mallard, two gadwall, and two pintail nests were in this category. No attempt was made to determine how long the hen would set on a nest before deserting. When it was found that the hen was setting on the nest longer than the normal incubation period the eggs were broken and the nest history completed. No nests of this type were located in 1952.

Parasitism

In this study 7.5 percent of the total number of duck nests found were parasitized by pheasants or by ducks of a species other than the nesting hen (Table 10). Fifty-three or 4.6 percent of the duck nests were parasitized by pheasants and 33 or 2.9 percent of the nests had interspecific parasitism. The 53 nests parasitized by pheasants contained 140 pheasant eggs of which 62 or 44.3 percent hatched. The 33 nests with interspecific parasitism held 86 parasitic duck eggs of which 11 or 12.8 percent hatched. Redheads parasitized 19 of the 33 nests, ruddy ducks seven, gadwall three, mallard two and cinnamon teal two. Only nests containing eggs of two or more species of ducks were recorded as interspecific parasitism. Intraspecific parasitism was not included because it is difficult to determine. If there was a way of accurately recording it the percentage of parasitized nests would show a notable increase, especially in redhead and ruddy duck nests. Twenty-one and four-tenths percent of the redhead eggs and 22.8 percent of the ruddy duck eggs found in hatched nests contained dead embryos. Fourteen and five-tenths percent of the hatched redhead nests and 18.5 percent of the hatched ruddy duck nests contained eggs with dead embryos in two or more stages of development. These percentages would be increased if it were known how many eggs were laid by the parasitic hen before the host hen started incubation. If the eggs laid by the host hen that contained dead embryos could be distinguished from those laid by the parasitic hen, a small decrease in the percentage would show. Fourteen and five-tenths percent of the redhead nests and 18.5 percent of the ruddy duck nests could be used as a minimum percentage of nests containing intraspecific parasitism. In the dabbling ducks only

TABLE 10
Parasitism on Duck Nests

Species parasitized	By pheasant				By ducks				
	Total nests	Nests		Eggs	Nests		Eggs	Total nests parasitized	
		No.	%		No.	%		No.	%
Mallard	395	17	4.3	40	11	2.8	33	28	7.1
Gadwall	277	28	10.1	82	3	1.1	5	31	11.2
Widgeon	2	--	--	--	--	--	--	--	--
Pintail	216	4	1.9	9	2	0.9	2	6	2.8
Cinnamon teal	37	--	--	--	3	--	17	3	8.1
Shoveler	67	3	4.5	8	1	1.5	1	4	6.0
Redhead	94	1	1.1	1	7	7.4	10	8	8.5
Ruddy duck	39	--	--	--	5	12.8	15	5	12.8
Lesser scaup	24	--	--	--	1	4.2	3	1	4.2
Total	1151	53	4.6	140	33	2.9	86	86	7.5

4.3 percent of the total eggs in the hatched nests contained dead embryos and only a fraction of one percent contained dead embryos in two or more stages of development.

The high percentage of gadwall nests parasitized by pheasants probably was due to their corresponding nesting peaks and a similar preference for nest sites.

Fate of Eggs and Clutch Size

In determining the fate of eggs and clutch size only data from successful nests were used. Eggs resulting from interspecific parasitized nests were included but all pheasant eggs were excluded. Eggs from nests that had hatched when first found also were included in determining the fate of eggs and clutch size. Nest histories on hatched-when-found nests were recorded only when the original clutch and fate of eggs could be determined accurately.

The average clutch size in 1957 was 9.6 eggs as compared to 10.3 eggs in 1952 (Table 11). A total of 9,343 eggs was produced from 976 successfully hatched nests of which 8,384 or 89.7 percent hatched (Table 12). Unhatched eggs remaining in nests were classified as infertile or containing dead embryos. The method used in determining these classifications is described in the 1952 study. Eggs that were infertile accounted for 203 or 2.2 percent of the total, and 602 or 6.4 percent of the eggs contained dead embryos. Of the remaining 144 eggs, 19 or 0.2 percent had hatched but the young were found dead in the nest. In comparing these figures with the 1952 study it is apparent that no major change had taken place.

TABLE 11
Comparison of Clutch Sizes Between 1952 and 1957

Species		Successful nests	Total eggs	Average clutch
Mallard	1952	178	1,622	8.9
	1957	316	2,804	8.9
Gadwall	1952	344	3,834	11.0
	1957	242	2,650	11.0
Widgeon	1952	--	--	--
	1957	2	20	10.0
Pintail	1952	41	376	9.2
	1957	196	1,556	7.9
Cinnamon teal	1952	32	343	10.2
	1957	28	287	10.3
Shoveler	1952	35	389	10.7
	1957	63	657	10.4
Redhead	1952	27	303	13.8
	1957	83	892	10.7
Ruddy duck	1952	8	64	8.0
	1957	27	268	9.9
Lesser scaup	1952	9	96	10.7
	1957	19	209	11.0
Total	1952	674	7,027	10.3
	1957	976	9,343	9.6

TABLE 12
Fate of Eggs in 1952 and 1957

Species	Hatched		Destroyed		Dead embryo		Infertile		Missing		Dead in nest		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Mallard	1483	91.4	6	0.4	79	4.9	26	1.6	28	1.7	--	--	1622	100.0
	2587	92.2	9	0.3	125	4.5	38	1.4	43	1.5	2	0.1	2804	100.0
Gadwall	3611	94.2	12	0.3	127	3.3	42	1.1	42	1.1	--	--	3834	100.0
	2459	92.7	--	--	97	3.7	47	1.8	42	1.6	5	0.2	2650	100.0
Widgeon	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	20	100.0	--	--	--	--	--	--	--	--	--	--	20	100.0
Pintail	347	92.3	--	--	19	5.1	7	1.9	3	0.7	--	--	376	100.0
	1408	90.6	--	--	69	4.4	58	3.7	19	1.2	2	0.1	1556	100.0
Cinnamon teal	303	88.4	--	--	31	9.0	3	0.9	6	1.7	--	--	343	100.0
	258	89.9	2	0.7	24	8.4	3	1.0	--	--	--	--	287	100.0
Shoveler	356	91.5	--	--	17	4.4	5	1.3	11	2.8	--	--	389	100.0
	621	94.4	--	--	25	3.8	5	0.8	5	0.8	1	0.2	637	100.0
Redhead	208	68.6	1	0.3	75	24.8	9	3.0	10	3.3	--	--	303	100.0
	649	72.8	6	0.7	191	21.4	45	5.0	--	--	1	0.1	892	100.0
Ruddy duck	45	70.4	--	--	18	28.1	--	--	1	1.5	--	--	64	100.0
	198	73.8	1	0.4	61	22.8	7	2.6	1	0.4	--	--	208	100.0
Lesser scaup	84	87.5	--	--	10	10.4	2	2.1	--	--	--	--	96	100.0
	184	88.0	1	0.5	10	4.8	--	--	8	3.8	6	2.9	209	100.0
Total	6437	91.6	19	0.3	376	5.4	94	1.3	101	1.4	--	--	7027	100.0
	8384	89.7	19	0.2	602	6.4	203	2.2	118	1.3	17	0.2	9343	100.0

TABLE 13
Frequency of Hatch by Date in 1957 *

Species	May						June						July						August						Total	
	2		12		22		2		12		22		2		12		22		2		12					
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%		
Mallard	--	--	9	2.8	21	6.6	58	18.4	73	23.1	119	37.7	26	8.2	10	3.7	--	--	--	--	--	--	316	100.0		
	--	--	--	--	--	--	--	--	3	1.2	125	51.9	67	27.8	38	15.8	5	2.1	3	1.2	--	--	241	100.0		
Gadwall	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2	100.0		
	--	--	--	--	--	--	1	50.0	1	50.0	--	--	--	--	--	--	--	--	--	--	--	--	2	100.0		
Widgeon	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	188	100.0		
	1	0.5	8	4.3	33	17.6	65	34.6	45	23.9	23	12.2	7	3.7	5	2.7	1	0.5	--	--	--	--	26	100.0		
Pintail	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	63	100.0		
	--	--	--	--	--	--	1	3.8	2	7.7	11	42.4	5	19.2	5	19.2	2	7.7	--	--	--	--	26	100.0		
Cinnamon	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	38	100.0		
	--	--	2	3.2	3	4.8	20	31.7	26	41.2	10	15.9	1	1.6	1	1.6	--	--	--	--	--	--	63	100.0		
Shoveler	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	38	100.0		
	--	--	--	--	--	--	2	5.3	2	5.3	3	7.9	8	21.1	8	21.1	11	28.8	3	7.9	1	2.6	38	100.0		
Redhead	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	17	100.0		
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	17	100.0		
Ruddy duck	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	24	100.0		
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	24	100.0		
Lesser scaup	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	915	100.0		
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	915	100.0		
Total	1	0.1	19	2.1	57	6.2	147	16.1	152	16.6	293	32.1	121	13.2	81	8.9	26	2.8	12	1.3	6	0.6	915	100.0		

* Figures under each date are numbers of nests that have hatched prior to that date and after and including the preceding date.

Hatching Dates

The peak of the hatch was during the ten day period from June 12 to 22 (Table 13). According to species, the pintail had the earliest peak which occurred during the period of May 22 to June 2. The ruddy duck was the latest with a hatching peak of July 22 to August 2. The first nest to hatch was that of a pintail during the period April 22 to May 2. The last nests to hatch were one redhead, four ruddy ducks and one scaup during the period of August 2-12. The first and last hatching dates are of those nests found on the study areas and are not necessarily the first and last hatching dates of all ducks on both refuges. One week old ruddy duck broods were observed as late as September 1.

Brood Data

A total of 1,839 one week old duck broods and 134 five and six week old duck broods were counted during the study. Little effort was made to count broods older than one week since it was quite apparent that brood grouping occurred after the first week of life. In areas of low nesting density brood regression would normally show but on an area such as Lower Klamath Refuge with a high nesting density the broods showed an increase in size after the first week, which is misleading. The five and six week column in Table 14 was included to show the increase in brood size. The average hatch per clutch in the 976 successfully hatched nests was 8.6 ducklings and by the end of the first week it dropped to 7.6. In 1952 the average hatch per clutch was 9.6 but during the first week it had decreased to 6.7, a loss of 2.9 ducklings. While in 1957 the average hatch per clutch was one duckling less than in 1952, the loss during the first week of life was only 12 percent as compared to 30 percent in 1952.

TABLE 14
Brood Counts *

Species	Average hatch per clutch	Average brood size	
		1 week	5-6 weeks
Mallard	8.2	7.2 (192)	7.6 (37)
Gadwall	10.2	7.9 (608)	8.2 (17)
Pintail	7.2	5.2 (70)	7.3 (22)
Cinnamon teal	9.2	6.3 (31)	-- --
Shoveler	9.9	7.5 (41)	10.3 (15)
Redhead	7.8	6.6 (385)	7.2 (37)
Ruddy duck	7.3	5.1 (107)	-- --
Lesser scaup	9.7	7.9 (105)	7.0 (6)
Average total	8.6	7.6 (1839)	7.8 (134)

* The numbers in parentheses are broods counted in each sample.

COOTS

The coot (*Fulica americana*) is a common nester on the marshes of Tule Lake and Lower Klamath Refuges. Its estimated breeding population is the largest of any single species of waterfowl on the areas.

Coot nests were abundant throughout the marsh, but only those on Unit 2 and 3 study areas were recorded. They were located by cruising along the edge of the marsh in an air-thrust boat.

Of the 94 coot nests located, 87 hatched for a nesting success of 93 percent. Seven nests were flooded for a total of 7 percent (Table 15). No nests were destroyed or deserted. The 87 successfully hatched nests contained 549 eggs of which 99.2 percent hatched, 0.4 percent contained dead embryos and 0.4 percent were missing (Table 16). The average clutch size was 6.3 eggs (Table 17). Twenty-nine of the 94 nests were floating without any concealment, and they were anchored to the bottom. In several cases, the nests were 100 yards or more out in open water away from the source of nest building materials. On July 20 wave action due to high winds flooded and completely demolished seven of these nests. Coot nests hatched from early June to the middle of August; the peak of hatching was during the period of July 2 to 12.

TABLE 15
Fate of Coot Nests in 1952 and 1957

Year	Hatched		Destroyed		Deserted		Flooded		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
1952--	141	94.6	2	1.3	1	0.7	5	3.4	149	100.0
1957--	87	93.0	--	--	--	--	7	7.0	94	100.0

TABLE 16
Fate of Eggs in Coot Nests in 1952 and 1957

Year	Hatched		Destroyed		Dead embryo		Infertile		Missing		Dead in nest		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1952-----	1087	97.5	4	0.4	19	1.7	2	0.2	2	0.2	--	--	1114	100.0
1957-----	545	99.2	--	--	2	0.4	--	--	2	0.4	--	--	549	100.0

TABLE 17
Clutch Size of Coots in 1952 and 1957

Year	Successful nests	Total eggs	Average clutch
1952-----	141	1114	7.9
1957-----	87	549	6.3

DISCUSSION

It was determined through the present nesting study that 678 or 78.7 percent of the 862 breeding pairs of Canada geese successfully hatched nests on the first attempt. The terminal brood size of four young multiplied by the 678 successful pairs resulted in a production of 2,712 goslings. It is the assumption of the authors that all unsuccessful nesting pairs will attempt renesting at least once. Therefore, 145 or 78.7 percent of the 184 unsuccessful nests times the terminal brood size of four young produces an additional 580 young and a total production of 3,292 Canada geese. By adding these 3,292 young to the 1,724 adults the fall population estimate of 5,016 Canada geese for Tule Lake and Lower Klamath Refuges was determined (Table 18).

The total production for ducks was 72,395 and the resulting fall population was 81,465. Coots had a production of 23,635 and a fall population of 33,135.

Tule Lake and Lower Klamath Refuges contain some of the finest waterfowl habitat, and maintain the highest nesting success of any area studied in California. Nest destruction by predatory mammals is the principal cause of nest failure in other areas of the state. On the Grasslands of Merced County in the San Joaquin Valley duck nest failure due to predation by mammals accounted for 61.7 percent of the nests in 1953 and 82 percent in 1954 (Anderson, 1956). Fifty-two and three-tenths percent of the nests studied in the Sacramento Valley in 1955 were destroyed (Anderson, 1957). Studies conducted on Honey Lake Refuge, Lassen County showed a nest destruction of 35.0 percent in 1951 and 34.3 percent in 1953 (Hunt and Naylor, 1955).

The low incidence of nest failure due to predatory mammals on Tule Lake and Lower Klamath can be attributed to two things: the absence or rare occurrence of the predatory mammals found in the Sacramento and San Joaquin Valleys such as the raccoon (*Procyon lotor*), spotted skunk (*Spilogale gracilis*), Virginia opossum (*Didelphis virginiana*) and Norway rat (*Rattus norvegicus*); and the large marsh areas containing islands with water barriers and stable water levels.

The California and possibly ringbill gulls are the main predators on the Tule Lake and Lower Klamath Refuges. Sixteen of the 19 destroyed Canada goose nests were the work of gulls. At least 20 of the duck nests found during the study were also broken up by gulls. The habit of Canada geese disregarding concealment in favor of a view of the surrounding habitat is probably why a higher percentage of goose nests than duck nests were destroyed by gulls. Unit 4 contained a nesting colony of 1,220 California gulls and 900 ringbill gulls. The Sheepy Lake area of Unit 2 also contained nesting colonies of approximately 400 gulls. While it is not too difficult to determine what percentage of nests are destroyed by gulls, it is not possible at the present time to determine what percentage of week old young are taken by gulls. It was mentioned before that one duckling per brood was lost during the first week of life, and on several occasions gulls were observed taking young, therefore, gulls could well be the major cause of the reduction in brood size on Tule Lake and Lower Klamath. The findings of this study are similar to those found in a study of gull predation on waterfowl in Utah. Odin (1950) concluded that 18.3 percent of the 2,997 waterfowl eggs in the 317 nests found during his

TABLE 18
Waterfowl Production

	Canada goose	Mallard	Gadwall	Widgeon	Pintail	Cinnamon teal	Shoveler	Redhead	Ruddy duck	Lesser scaup	Coot
Breeding pairs-----	862	2,370	2,100	10	916	640	312	2,770	1,300	472	4,750
Average nesting success-----	78.7	80.0	87.4	100.0	90.8	75.7	94.0	88.3	69.2	79.2	93.0
Successful pairs-----	678	1,896	1,835	10	832	484	293	2,446	900	374	4,418
Terminal brood size-----	4.0	6.8	7.2	7.0	5.0	6.2	7.0	6.4	5.0	7.0	5.0
Result of one nesting-----	2,712	12,883	18,212	70	4,160	3,001	2,051	15,654	4,500	2,618	22,090
Pairs re-nesting-----	184	474	265	--	84	156	19	324	400	98	332
Average nesting success-----	78.7	80.0	87.4	--	90.8	75.7	94.0	88.3	69.2	79.2	93.0
Successful pairs-----	145	379	232	--	76	118	18	286	277	78	309
Terminal brood size-----	4.0	6.8	7.2	7.0	5.0	6.2	7.0	6.4	5.0	7.0	5.0
Result of second nesting-----	580	2,577	1,670	--	380	732	126	1,830	1,385	546	1,515
Total young produced-----	3,292	15,460	19,882	70	4,540	3,733	2,177	17,484	5,885	3,164	23,635
Adults-----	1,724	4,740	4,200	20	1,832	1,280	624	5,540	2,600	944	9,500
Resulting population-----	5,016	20,200	24,082	90	6,372	5,013	2,801	23,024	8,485	4,108	33,135

Total Fall Duck Population 81,465

study were destroyed by California gulls. Nest concealment and distance from the gull colony were the main factors in determining the amount of destruction. He also noted that in the stomach analysis of 90 California gulls, 18 contained young waterfowl, embryos, down and egg shells.

SUMMARY

1. A study was made of nesting Canada geese, ducks and coots on Tule Lake and Lower Klamath Refuges during the waterfowl nesting season of 1957.
2. A total of 267 goose nests, 1,151 duck nests and 94 coot nests were located and studied.
3. The hatching success of Canada geese was 78.7 percent, with 12.7 percent of the nests deserted, 7.1 percent destroyed and 1.5 percent flooded. The average clutch was 5.5 eggs. The average number of eggs hatched was 4.8. The nesting period for Canada geese lasted approximately 79 days, with the peak of hatch during the period from April 22 to May 2.
4. The hatching success of all ducks was found to be 84.8 percent. Shovelers had the highest success with 94 percent and ruddy ducks the lowest with 69.2 percent. The principal causes of nest failure among the ducks were desertion 7.8 percent and predation 6.6 percent. In successfully hatched nests 89.7 percent of the eggs hatched, 6.4 percent contained dead embryos, 2.2 percent were infertile, 1.3 percent were missing and 0.2 percent hatched but the young were found dead in the nest. The first nest hatched during the period April 22 to May and the last nest to hatch of those studied, hatched during the period August 2 to 12. The peak of hatch occurred between June 12 and 22. The average clutch was 9.6 eggs. The average hatch per clutch was 8.6 ducklings which were reduced to 7.6 ducklings per brood during the first week of life.
5. Ninety-four coot nests were located of which 93 percent hatched and seven percent were flooded. In the successfully hatched nests 99.2 percent of the eggs hatched, 0.4 percent contained dead embryos and 0.4 percent were missing. The average clutch consisted of 6.3 eggs. The peak of hatch occurred during the period of July 2 to 12.

ACKNOWLEDGEMENTS

The authors wish to thank the following California Department of Fish and Game personnel: Morris Anderson, Wayne Long, Nicholas Masellis, Dick Wagner and George Wurst for help in collecting field data; Frank M. Kozlik, A. W. Miller and A. E. Naylor for guidance in manuscript preparation; and Cliffo Corson who prepared the maps. Also, there is appreciation for the assistance and cooperation of the following personnel of the Bureau of Sport Fisheries and Wildlife: Jean Branson and Thomas Horn, and especially LeRoy Giles who collected most of the data on breeding pairs and brood survival.

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NOTE

Propagation of Quail Brush (*Saltbush*)

In semi-arid central and southern California, especially where the average annual rainfall is below 10 inches, the natural, original plant cover on some large areas, was presumably a shrub-grassland with quail brush, *Atriplex*, the dominant shrub. In places this shrub-cover remains to indicate its former status, but most of the grasses and forbs that were its aboriginal associates are gone, replaced by alien plants of old-world origin.

Over much of its former range the quail brush, too, is gone, removed in the development of cultivated croplands or other forms of modern land-use. Its principal cause of extirpation, however, has been through livestock grazing. Its most favored ranges were the drier, inland valleys and lowlands, of deep alluvial soils, where extreme periods of drought normally occur. Quail brush is adapted to these conditions mainly by a deep root system through which it draws moisture from the sub-surface strata. Not only does this enable it to flourish in dry years, but it also explains its habit of growing, blooming, and producing seed in the dry, California seasons of summer and fall. During this rainless period when its associated annual plants are generally dry and dead, the quail brush puts out new growth that is succulent, nutritious, and palatable livestock forage. This makes it extremely vulnerable to ill-advised grazing practices. Some range programs are known in which quail brush is thriving after many years of liberal range use, however, the intensive year-round grazing that is customary throughout its general range has destroyed all but a few stands of this shrub.

In a program to rehabilitate the quail populations of this same region, protective ground cover has been found to be a principal need. Dense stands of this plant grown from seed have established successfully and have proved to be the ideal protective cover for California quail. One hedge of this shrub (Figure 1), approximately 200 feet long and eight feet wide has been the exclusive daytime, winter covert of a covey that in recent seasons has numbered from 400 to 600 birds. This hedge was planted in 1952 and was well matured after four years growth.

Transplanting the seedling shrubs has been done and may be advisable where only a few plants are wanted, however, propagation from the seed is much more practical and successful for cover patches or general range rehabilitation. The seeds are produced in dense clusters on the outer tips of the branches and mature in late fall. December is a good time to gather them. They can be collected easily by stripping the outer branches so that the seeds fall on a canvas or cloth stretched on the ground.



FIGURE 1. Gathering seed from a strip of *Atriplex polycarpa*. Photograph by I. I. McMillan.



FIGURE 2. After broadcasting the seed on the surface of cultivated ground, a light drag, smoothing and packing the seedbed is used to incorporate the seed with surface soil. Photograph by I. I. McMillan.

At least four species of *Atriplex*, native to California and this region can be used. The species *A. lentiformis* and *A. breweri* are the largest and quickest growing,⁹ but require more moisture than *A. polycarpa* or *A. canescens*. *A. polycarpa* has the widest range in central California and is evidently the best adapted to propagation as quail cover. The practices specified here are mainly in reference to it, but the other three species mentioned also have been successfully grown in the same way.

The seed-bed for planting quail brush should be prepared so as to resemble the natural conditions in which it prefers to germinate, i.e., bare, smooth ground. Some successful plantings have been made by merely scattering the seed on bare range land that had been denuded by extreme grazing. For maximum success, however, the planting site should be cultivated prior to seeding in such a way as to establish a fine mulch, preferably not more than three inches deep. After the first fall or winter rains, preferably in late January, and with all vegetation killed by cultivation, the seed can be sown by broadcasting it on the surface. Following this, a light drag (Figure 2) that will merely incorporate the seed with the surface soil, and at the same time pack and smooth the seed-bed has been most effective. The general principle to follow is that the seed of quail brush, as with some other arid-land species may need to be at or near the surface in order to germinate, and it prefers a firm, smooth, well packed seed-bed, free of other plants.

The amount of seed to be used depends on the type of stand desired and the rainfall of the area as well as the species selected. On open range and for an open stand of the shrub, much less seed is needed than for a dense patch of quail cover. A rate of 100 pounds per acre of *Atriplex polycarpa* seed is adequate for a thick stand.

Seasonal weather is a prime factor in germinating the seed of this highly specialized, native plant. It has survived by saving its seed for weather conditions that only occasionally occur in its natural, semi-arid range. These weather conditions are those of adequate rainfall which promise sustained, year-long growth for a seedling perennial shrub. A program of propagation should include the provision for continued plantings in case of initial failure.

After germination, quail brush is thrifty and hardy, and needs no further cultivation or care except that it must be protected from damage by sheep or cattle. After it is established, however, the right amount of browsing actually stimulates growth and does not damage the plant. Plantings can be made in narrow strips and by cultivation of the borders of these strips to eliminate the competition of other plants, the growth rate of the quail brush will be greatly increased.—*I. I. McMillan, Rancher, Shandon, California, May, 1960.*

IN MEMORIAM

BRIAN CURTIS

Brian Curtis, former editor of *California Fish and Game Quarterly*, died unexpectedly as the result of a heart attack at his home, Faradawn, St. Helena, California, on September 5, 1960, at the age of 66. At the time of his death, he was fishery consultant to the Pacific Gas and Electric Company.

Mr. Curtis joined the California Division of Fish and Game, precursor of the present department, in 1937, as a senior member of the biological staff of the Bureau of Fish Conservation (now the Inland Fisheries Branch). Prior to this, he had enjoyed an extremely interesting and varied career.

Following graduation from Harvard University in 1915, he studied civil engineering at the Massachusetts Institute of Technology. He joined the French Ambulance Service early in World War I, and later served in the U. S. Army as an artillery officer. Following his discharge with the rank of captain, he engineered a number of bridges in Colombia and Venezuela, and after that engaged in free-lance writing. Later, his growing interest in fisheries biology resulted in a thesis and advanced degree at Stanford University, with the Golden Trout as his subject of study.

From 1937 to 1940 he served as biologist in the Lake Tahoe area, as a start was then being made to organize the Bureau of Fish Conservation on a district basis. In December, 1940, Mr. Curtis was appointed to the newly created position of Supervising Fisheries Biologist, in which capacity he served until his retirement on September 30, 1948. During these eight years he supervised the organization and work of the biological staff of the Bureau of Fish Conservation. Even though his staff was reduced to three district biologists during World War II, he was able to lay the foundation for the later rapid expansion of the group when manpower again became available.

Mr. Curtis will long be remembered for his delightful book, "The Life Story of the Fish: His Morals and Manners," the booklet "The Warmwater Game Fishes of California," and many other writings.

Mr. Curtis is survived by his wife, Meta, to whom the sincere sympathies of all who knew and worked with him are extended.—*Leo Shapovalov, Senior Fisheries Biologist, Inland Fisheries Branch, California Department of Fish and Game, September, 1960.*

BOOK REVIEW

Marine Biology

Edited by B. N. Nikitin; American Institute of Biological Sciences, Washington, D. C., 1959; 302 pp., \$10.

The title suggests a volume on the natural history of marine organisms, while, in fact, it is a translation of 13 individual papers originally published as Volume 20 of the Transactions of the Institute of Oceanology of the U.S.S.R. Academy of Sciences, Moscow, 1957. These papers cover a wide range of subject material as indicated by the titles listed below.

1. General review of the bivalve mollusks of the northern seas of the U.S.S.R.
2. The euryhalinity of some species of the Black Sea benthos and the possibility of their settlement in the Sea of Azov.
3. Biological aspect of the bottom fauna groupings of the North Okhotsk Sea.
4. Food interrelationships of dominant species in marine benthic biocoenosis.
5. Hyperiid (Amphipoda) of the Northwest Pacific Ocean. 1. Tribe Hyperiidea Physosomata.
6. Zooplankton of the West Kara Sea and Baidaratskaya Bay.
7. Distribution of zooplankton in the southern half of the Tartary Strait (from the collection of May 1951).
8. The spatial interrelationships of marine zoo and phytoplankton.
9. The feeding of some carnivorous deep-sea benthic invertebrates of the Far Eastern Seas and the Northwest Pacific Ocean.
10. Age and growth of the navaga (*Eleginus*) in the Kara Sea.
11. Young flatfishes (Pleuronectidae) of the Far Eastern Seas. 2. Distribution, age and growth.
12. Growth and age of deep-water fishes.
13. Notes on the development of the Far Eastern navaga (*Eleginus gracilis* Tilesius).

The AIBS Committee on Translations has made available to the English speaking scientists a small amount of the Russian fisheries literature in this publication. Although the cost of translating runs high I feel the price of \$10 does not make this book a bargain. It certainly should be available in libraries for reference work but would be put to only limited use by most fisheries biologists.—*E. A. Best, California Department of Fish and Game.*

Alaska In Transition—The Southeast Region

By George W. Rogers; Johns Hopkins Press, Baltimore, Maryland, 1960; xiv plus 384 pp., illus., \$7.

Dr. Rogers has studied southeast Alaska for fourteen years as a professional economist and a resident. His report objectively presents the geographic, economic and political setting of the Region. Political manipulation of the Region's resources is described in detail with numerous quotations from government files, newspaper articles, and published data. References quoted are listed in footnotes. Some government agencies may be quite embarrassed by the straightforward reporting in this book.

The first four chapters give the reader the feeling of the Region. In the last three chapters the author picks out the most strategic elements in the future development of the Region and suggests what can or may be done for economic and social stability. Throughout the book the theme is transition—the declining salmon fishery, the economic and social welfare of the Indians to whom the shortage of salmon can mean disaster, and the present and future aspects of forest management as an economic base for the Region.

Aside from primary purposes, the book is an excellent history of the Alaska salmon industry. The primitive Indian fishery, the establishment of canneries, the source of new species after another, bureaucratic bungling, lobbying and political bribery by the fishing industry, and the lack of adequate biological research are presented in relation to their importance in the failure of the Region's main economic base. The salmon industry controversy is discussed early in the book and reference is made to it throughout the text.

Mr. Rogers has hope for a viable economy based on forest products. His description of U. S. Forest Service policies and management in southeast Alaska gives the reader a favorable impression of that agency. Unless, of course, the reader is dedicated to total destruction or total preservation of natural resources in preference to sustained yield use.

Apparently there are several aspects of southeast Alaska's economic and social transition that can not be accurately forecast. Can the salmon runs be increased through research and management? Will the Indians be able to shift their cultural and economic patterns from fish to forest? Will the Region's natural resources be developed primarily for resident needs, as the Forest Service would do, or for transient needs as the fish packers did?

Alaska Is Transition was sponsored by the Arctic Institute of North America and Resources for the Future, Inc. The subject matter is important to everyone.—*Richard Haley, California Department of Fish and Game.*

The Forest Ranger

By Herbert Kaufman: The Johns Hopkins Press, Baltimore, 1960; 259 pp., \$5.

This work adds to the growing body of case studies which are accumulating facts and conclusions about the internal mechanics of organizations. It will be of unusual interest to readers of this journal, because of the agency studied. The U. S. Forest Service has long been notably successful among Federal agencies of all types and among conservation agencies at all levels of government.

In making his study, Kaufman spent a week or more with each of five rangers in their field headquarters. The ranger districts involved were scattered over the country. A Westerner might have selected more than one district west of Colorado; however, for present purposes, the preponderance of eastern samples was not unreasonable.

The book reflects a deep enough understanding of the Service at all levels to encourage confidence in the observations and the conclusions developed from them.

In the author's words, the book "... describes the tendencies toward fragmentation of the Forest Service, the factors that operate to break it up into its component units and render each an independent miniature of the agency as a whole. Chapter II takes up the centrifugal tendencies inherent in the magnitude and character of the work of the Forest Service, and in the characteristics of the organization required to discharge its responsibilities. Chapter III deals with centrifugal tendencies with which most large organizations, regardless of the nature of their work, must contend, and with some special elements in Forest Service history that accentuate these tendencies.

"Part Two then lists the factors that tend to hold the Forest Service together, to integrate the activities of its personnel, to forge a national policy in the face of circumstances conducive to many local, unrelated policies. Chapter IV treats the means by which field decisions are in effect made in advance for field officers. Chapter V discusses the methods of holding field behavior in the channels thus established regardless of the preferences of field officials. Chapter VI examines the techniques that result in field officials doing of their own volition the things the leaders of the Forest Service want them to do.

"... Chapter VII is an attempt to put the pieces together, to capture them in motion, to study their interplay, and, from this analysis, to derive the lessons to be learned from Forest Service experience and from this way of approaching it."

The heart of the book is a detailed description of the many mechanisms within the Service which insure enthusiastic conformity with headquarters' objectives and procedures, as well as whole-hearted identification with the Service. The entire pattern is quite remarkable from an administrative standpoint because of its great success and its willing acceptance by the individual rangers.

Fish and game administrators with organizational or operational problems will find this an unusually stimulating book. Forest Service methods for unifying personnel and insuring field compliance with agency goals and policy, are generally more effective than comparable state fish and game department methods. There are many reasons for this and, in many cases, there is no possibility for a fish and game depart-

ment to follow the approach which has been so successful in the Forest Service. However, a great deal is applicable, and other conservation agencies can learn much from Forest Service experience and from the principles and patterns of organizational behavior that this experience reveals through Kaufman's study.—*Alex Calhoun, California Department of Fish and Game.*

Fisherman's Summer

By Roderick Haig-Brown; William Morrow & Company, New York, N.Y., 1959; 253 pp., illustrated by Louis Darling, \$3.75.

It is possible that some people can ignore Mr. Haig-Brown's writings or dismiss his books with a bored yawn. I must confess, however, that I am not one of these. The old master writer and angler has hooked me solidly, and I look forward with undisguised eagerness to any new material from his pen.

The heart of the book contains arguments which should interest all anglers and fishery biologists. The chapter on *The Launchbreaker* takes a wry poke at the strong emphasis placed on harvest by those fishery managers who would "manage" solely on a biological basis: the angler who hooks and releases a fish is a violator! In *Signs of the Times* there is an excellent and most corrosive satire on the increasingly popular fish derbies. Here, also, is a justifiable complaint against the Sport Fishing Institute's familiar motto "To Shorten the Time Between Bites."

The latter comment introduces a theme which has run through many of Mr. Haig-Brown's books. The real basis for fishing should be sport, and in turn, sport should be made up of *tradition, ethics and restraint*. These things give meaning and satisfaction to angling. If only efficiency were considered, fishing as a sport would (or should) die a natural death. Emphasis should be placed on the quality of the sport and the pursuit of personally acquired skill, developed over years and stimulated by dreams.

It is amazing how many other topics have been briefly exposed by the author to whet one's appetite. There are comments on *The Great Destroyers*—the widespread use of insecticides, the giant water projects, and the hydroelectric dams. There is a plea to consider restricting all trout and steelhead streams to artificial lures only. And to the biologist's great satisfaction, here is one popular writer who both understands and is willing to use the technical characteristics necessary to identify closely related fish species. He does not fear or scorn use of terms like "anal fin ray counts," "gill rakers" or "pyloric caeca." The eastern fisherman will also be pleased with Haig-Brown because he includes some experiences on the famous Beaverkill in New York State and the historic chalk streams of England.

While the major part of the book is concerned with British Columbia, the eastern fisherman will feel a certain nostalgia as Haig-Brown covers experiences on the famous Beaverkill in New York State. And any fly fisherman can readily identify with the historic chalk streams of England.

There's something here—in fact a great deal—for anyone with a love of fishing.—*Herbert E. Piatler, California Department of Fish and Game.*

How to Make Fish Mounts and Other Fish Trophies

By Edward C. Migdalski; The Ronald Press Company, New York 10, N. Y., x + 218 pp., illustrated with 190 black and white photographs, \$5.50.

The title of this book might lead one to believe that this is a guide for those interested in the art of fish taxidermy. The reader will be surprised to find that only one of the 12 chapters is devoted to the techniques of skinning and mounting fish specimens, or in popular parlance "stufing" fish.

Author Migdalski, who has spent many years as an ichthyologist and preparator at the Bingham Oceanographic Laboratory and the Peabody Museum of Natural History at Yale University, has described various ways of preparing fish trophies and illustrated each method with a series of remarkably clear photographs. The technique of preparing a plaster mold of a fish and then casting an accurate likeness of the specimen is very well explained. However, should this method prove to be too difficult or time consuming, the reader is encouraged to turn to one of the methods requiring less skill, such as making outline drawings and silhouettes on art board or effective fish photographs. The entire chapter describing a particular method should be studied before commencing work, otherwise one is apt to experience difficulty. For example, the instructions for mixing plaster of Paris for a mold appear before the directions for preparing the fish specimen used in making the mold. Obviously, the specimen should be made ready to receive the quick setting plaster before it is mixed.

Painting mounted fish and casts has long been a bugaboo even to professional taxidermists. Unfortunately, the chapter on painting the mounted specimen or cast offers no simple means of exactly duplicating the coloration of some of our varied colored game fish such as rainbow or eastern brook trout. For one who has little or no artistic ability, it would be well to consider the author's suggestion to paint the mount or cast a solid color such as gold or black.

This book will be of interest to the sportsman who desires a tangible record of a trophy fish prepared through his own efforts. Instructors at summer camps, boy scout leaders, and teachers will find that this volume is a valuable source of new ideas for their nature and craft programs.—*George H. Warner, California Department of Fish and Game.*

This Is the American Earth

By Ansel Adams and Nancy Newhall; Sierra Club, San Francisco, 1960; xviii plus 89 pp., \$15.

This is the story of mankind, conservation and wilderness preservation expressed in a true symphony of word and picture. In a most artistic manner the authors have created an intriguing combination of poetically expressed philosophy and superb illustrations representing the acme of the photographer's art.

The theme emphasizes man's relationship with the natural world, his despoilment and alteration of its lands and waters in his search for material wealth and happiness.

Justice William O. Douglas said of this book, "I hope millions read this volume. We have only a little time in which to prevent our remaining natural heritage from being fed into the hungry maw of the industrial machine. Some of the unmarked face of America's wilderness must be left as a refuge for man—as a place where he can escape the roar of machines and once more get on understanding terms with the universe."

No one who possesses any appreciation for the out-of-doors can fail to be impressed by this fine pictorial word poem and ponder deeply over the philosophy of life expressed here.—*Willis A. Evans, California Department of Fish and Game.*

Complete Field Guide to American Wildlife. East, Central and North.

By Henry Hill Collins, Jr.; Harper and Brothers, New York, 1959; xix + 683 pp.

Profusely illustrated with line drawings, black and white plates, range maps and 48 color plates. \$6.95 (Deluxe edition \$7.95).

This book is truly a comprehensive work for seldom is so much information contained in a volume of this small size. It is designed to provide rapid field identification of "all species of birds, mammals, reptiles, amphibians, food and game fishes, sea shells and the principal marine invertebrates occurring annually in North America east of the Rockies and north of the 37th parallel."

The text includes descriptions and comments on ecology, behavior, food, reproduction, evolution, adaption and conservation as well as where to find and how to care for many of the various creatures in captivity.

Birds are considered first with approximately one-third of the book devoted to the subject. There are many range maps, line drawings, comparison charts and color illustrations of the species covered, as well as illustrations of the general coloring and shapes of the eggs of each. Numerous lines of verse and historical notes are included from time to time, as with the Blackburnian Warbler on page 206.

The chapters on mammals, reptiles, amphibians, etc., which follow are equally well presented along the same general outline but tend to become progressively abbreviated, especially so with the invertebrates. Unfortunately, the fidelity of many of the color plates leaves much to be desired, particularly so with the mammals. Also, it is rather disconcerting to find color plates of birds included with those of bats and some of the other mammals.

Typographical errors are almost non-existent, one exception occurring on page 11, line one, under "Useful References." The tabular index system of locating various specific chapters without having to refer to the standard index is a very useful innovation well adapted to a book of this scope. Generally speaking, the book fulfills the intended purpose of providing "comprehensive and authoritative information for on-the-spot identification of every form of wildlife you will see in the course of a day's walk . . . a camping trip . . . an entire vacation" very well, and while it is designed primarily for use "east of the Rockies and north of the 37th parallel" it should also prove quite useful to amateur naturalists as well as professional field biologists here in the western United States.—*William D. Hawes, California Department of Fish and Game.*

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O

STATE OF CALIFORNIA
FISH AND GAME COMMISSION

Notice is hereby given, pursuant to Sections 206, 207, 208 of the Fish and Game Code, that the Fish and Game Commission shall meet on October 4, 1960, in Room 3191, State Capitol Building, Sacramento, California, to receive recommendations from its own officers and employees, from the Department of Fish and Game and other public agencies, from organizations of private citizens, and from any interested person as to what, if any, regulations should be made relating to fish, amphibia, and reptiles, or any species or sub-species thereof.

FISH AND GAME COMMISSION
Wm. J. Harp
Assistant to the Commission

Notice is hereby given, in accordance with Section 206 of the Fish and Game Code, that the Fish and Game Commission shall meet on December 9, 1960, in the State Building Auditorium, First and Broadway, Los Angeles, California, to hear and consider any objections to its determinations and proposed regulations in relation to fish, amphibia, and reptiles for the 1961 angling season, such determinations and orders resulting from hearing held on October 4, 1960.

FISH AND GAME COMMISSION
Wm. J. Harp
Assistant to the Commission